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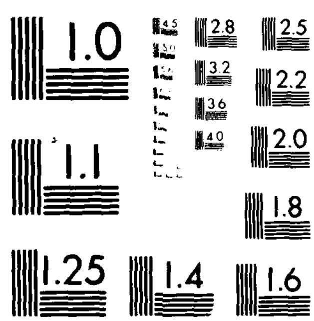

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EVALUATION OF SURFACE DUCTS IN SHALLOW WATER

J. A. Whitney
D. F. Gordon
J. G. Colborn

29 March 1982

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Nine shallow water areas of strategic interest were selected for a preliminary study of surface ducts in shallow water. The objective was to determine the relative percentage of surface ducts versus downward refractive conditions. Sound speed profiles from National Oceanographic Data Center (NODC) Nansen cast files and XBT profiles were classified by computer as either positive or negative (non-positive) gradient profiles. Ninety percent of the fall-winter and 31 percent of the spring-summer profiles were of positive gradient (or surface duct) type. Percentages are given for each of the nine cases.

Representative profiles and sea floor data from six of the sites were used to compute propagation loss. These losses, computed by normal mode theory, were used to determine the frequency of optimum propagation

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at these sites for positive and non-positive gradient profiles. Positive gradient (winter) profiles generally resulted in at least 10 dB less loss at 50 km range than did non-positive gradient profiles. Optimum propagation for positive gradient surface ducts varied from 200 to 1000 Hz.

The reflectivity of the bottom models varied greatly. Where propagation was relatively good by bottom reflected paths, optimum frequencies were around 500 Hz. The greatest differences between propagation losses calculated for the positive and non-positive profile cases are seen where such reflectivity is poor.

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BACKGROUND

OBJECTIVE

The objective of the program underlying this work is to determine the relative percentage of positive gradient surface ducts versus downward refractive conditions for shallow areas of strategic interest, determine frequency regimes of optimum propagation corresponding to sound speed profile classification and correlate them with geographic and seasonal distributions.

RESULTS

1. Nine shallow water areas were examined for the presence of positive sound speed gradients. Ninety percent of the fall-winter sound speed profiles and 31 percent of the spring-summer profiles were of the positive gradient type.

2. Positive gradient (winter) profiles generally resulted in at least 10 dB less loss at 50 km range than did the negative gradient (summer) profiles.

3. Three of the areas, North Sea, Strait of Juan de Fuca and Lands End, in which propagation losses were calculated, had coarse-grained surface sediments resulting in small bottom reflection losses and relatively good propagation by bottom reflected paths. In these cases optimum propagation is in the 500 Hz frequency range.

4. Optimum frequencies of propagation for positive gradient surface ducts varied from 200 to 1000 Hz.

5. When a surface duct exists in shallow water it can dominate the propagation and lead to a completely different optimum frequency of propagation. However, high bottom loss is required to demonstrate this effect. This is illustrated at the East of Singapore site.

6. A change in the magnitude of the compressional wave attenuation in the sediment model produces a proportional change in the bottom reflection loss and can lead to large changes in the calculated propagation loss. This was evident in the Straits of Sicily calculations.

7. Propagation by bottom reflected paths is a very sensitive function of sediment types. Sediment models used here produced propagation ranging from very good to very poor. Many details of this propagation in the frequency domain were unexpected.

RECOMMENDATIONS

1. The prevalence of surface ducts in shallow water needs to be determined in many more areas.

2. The relative dominance of a surface duct when present in shallow water propagation needs further clarification.

3. Since bottom reflection loss is a large factor in shallow water propagation the dependence of bottom loss on sediment properties, particularly attenuation, should be determined more precisely.

4. Include surface scattering in an assessment of surface duct versus bottom reflected paths.

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1. INTRODUCTION

1.1 Intent of Report

This report will give the results of a study of sound velocity profiles in shallow water for a limited number of sites. The sites considered here are located on continental shelves or shallow sea areas and with two exceptions are limited to water depths of 200 meters (m), a nominal depth limit for shallow water. The relative percentage of surface duct versus downward refractive conditions is determined for different seasons and various geographical areas. Sediment models in certain areas allowed normal mode calculations to determine optimum frequency domains for sound propagation at those sites.

1.2 Background

Ten shallow water stations were occupied during the FASOR cruises, to the south and western Pacific and adjacent areas in the 1960s. Seven of those stations (Reference 1) had sound speed profiles with significant surface ducts, i.e., positive gradient surface layers. Only three of these stations had strong surface ducts, whereas three were downward refracting. It is noteworthy that five stations with moderate to strong surface ducts were run in May, June or July and lie within 12 degrees of the equator. Although these data are limited, they demonstrate that surface ducts may be more prevalent in shallow water then previously considered.

Propagation characteristics will differ markedly in shallow water with downward refraction. In the surface duct case there is little interaction with the bottom and the optimum frequency for sound propagation will be relatively high, depending primarily on the duct depth. For example, the optimum frequency for a 100-ft isothermal duct is approximately 2 kHz. In contrast, the bottom characteristics are the critical factors for the case of downward refraction. Since at low frequencies the principal loss mechanism is the attenuation of the sound waves in the bottom sediments and this attenuation is a linear function of the frequency (Reference 2), the optimum frequency is expected to be quite low.

In 1976 M. A. Pedersen and D. White (Reference 3) selected two of the FASOR shallow water stations for an optimum frequency study. Results for a downward refraction profile were compared to optimum frequencies for the surface duct case. While their results support the contention that optimum frequencies will be less for downward refraction cases, the problem of optimum frequencies for shallow water needs additional study. Also for considerations of future shallow water sonar systems it would be valuable to determine the geographical areas and times of year when surface ducts are prevalent in shallow water areas.

1.3 Organization of Report

The selection of the sites, the methods of assessment and classification of sound speed profiles and the selection of representative profile types are discussed in Section 2. Also an introduction is given to the propagation loss calculations and optimum frequency determination.

---

1. Propagation Losses and Reverberation from the Shallow-Water FASOR Areas with Comparisons to Propagation Loss Models, J. A. Whitney, Naval Ocean Systems Center TR 400, March 1979.
2. Compressional-Wave Attenuation in Marine Sediments, E. L. Hamilton, Geophysics, Vol 37, No. 4, August 1972.
3. Reference available to qualified requestors.

Results are presented in Sections 3 and 4. Section 3 contains the physical descriptions of the sites, the representative profiles, a summary of the sound speed profile statistics and bottom sediment characteristics. Acoustic results are given in Section 4 where propagation loss calculations are presented and comparisons are made. Optimum frequencies for the representative, seasonal profiles are discussed. Concluding remarks are given in Section 5.

2. PROCEDURES

2.1 Site Selection

The locations of the shallow water areas discussed in this report are given in Table 2.1. These sites were selected for evaluation based on expected differences in environmental types. Selection is limited in part by availability of sound velocity profile (SVP) data in data banks and/or available sea floor sediment data. Of course, this is only a partial list of possible shallow water sites of interest to the Navy. A more complete list might contain 30-40 individual sites.

Site	Latitude	Longitude
A. North Sea	57.5°-59.0°N	1.5°-2.5°E
B. Strait of Juan de Fuca	48°-49°N	125°-126°W
C. East of Singapore	0-2°N	105°-109°E
D. Lands End	49°-51°N	8°-10°W
E. Korea Strait	32°-34°N	126.5°-128.5°E
F. Straits of Sicily	36°-38°N	11°-13°E
G. Shallow of Bering Sea	56°-59°N	165°-169°W
H. Bass Strait	39°-41°S	145°-149°E
I. North Coast of Brazil	0°-2°N 2°-4°N	46.5°-49°W 47.5°-50°W

Table 2.1. Locations of shallow water sites.

The first four sites (Table 2.1) were chosen in 1980 for a preliminary study. The Strait of Juan de Fuca represents a mid latitude site coupled strongly with the open ocean with potential brackish water influence. The site East of Singapore is an example of an equatorial environment within a large area of shallow water. Seasonal effects at low latitudes are naturally expected to be weak compared to those at mid to high latitudes. The shallow North Sea site is an example of an isolated adjacent sea located at high latitudes. The Lands End site is positioned on a wide (continental) shelf at relatively high latitudes, exposed to open ocean conditions and influenced by the North Atlantic current extension of the Gulf Stream.

The sites in the Straits of Sicily and the Korea Strait were added as areas of high operational interest. The submarine ridge between Sicily and the continent of Africa, the Straits of Sicily, separates the Mediterranean into two main basins. The eastern basin is a

concentration basin* with respect to the western basin. The exchanges of water through the Straits of Sicily are similar to those between the Mediterranean Sea and the Atlantic Ocean. The currents are less complex due to the broad extent of the Straits of Sicily relative to the Strait of Gibraltar and to the greater difference in the mean salinities of the Mediterranean and the Atlantic water. The Korea Strait site is on the broad continental shelf off China and under the influence of the Kuroshio current from the south and the intrusion of cold water from the Sea of Japan to the northeast.

The shallow Bering Sea is a high latitude site within a large, flat area of shallow water between 50 and 150 m and one in which propagation loss tests have been reported (References 4, 5). The site in the Bass Strait was added to extend the coverage into southern latitudes. The site near the mouth of the Amazon River is on the continental shelf off the coast of Brazil under the influence of the open sea and the outflow of the Amazon. This site is similar in those respects to the Juan de Fuca site but differs in latitude and depths of water.

These sites are located on a world map in Figure 2.1 (the actual place is called out in alphabetical order as listed in Table 2.1) and on surrounding area charts in Figure 2.2.

2.2 Sound Speed Profiles

The purpose of the sound speed profile selection process as described below was two-fold. The first was to provide reliable estimates of the occurrence of surface ducts in shallow water areas for different times (seasons) of the year. The second was to determine characteristic profiles to represent an area for use in normal mode calculations of propagation loss.

2.2.1 Assessment

The primary source of sound speed data for this study was the National Oceanographic Data Center (NODC) Nansen cast archival data file. This file provides profiles of ocean temperature, salinity and computed sound speed at standard depths of 0, 10, 20, 30, 50, 75, 100, 150 and 200 meters (Wilson's October sound speed equation (Reference 6) is used). To supplement the number of available profiles, the NODC archival XBT data file was searched for suitable temperature profiles. These profiles were then converted to sound speed profiles using the annual mean salinity profile from the Nansen cast data at that site and then were interpolated for sound speed at standard depths. The XBT data contributed significantly to the sample size in several cases, especially at the site East of Singapore. The XBT data were not used at other sites where ample Nansen cast stations were available. XBT data were used to increase the sample size in four different instances.

*The amount of evaporated water exceeds that gained by the precipitation and river discharges. The entire Mediterranean is a typical example of a concentration basin.

4. LORAD Tests in the Shallow Bering Sea, J. A. Whitney, Naval Electronics Laboratory Report 1160, February 1963.
5. Long-Range Acoustic Propagation in the Shallow Bering Sea, K. V. Mackenzie, Naval Undersea Center TP 293, June 1972.
6. Equations for the Sound Speed in Sea Water, W. D. Wilson, J. Acoust. Soc. Am., Vol 32, 1960, p 1357 (L).

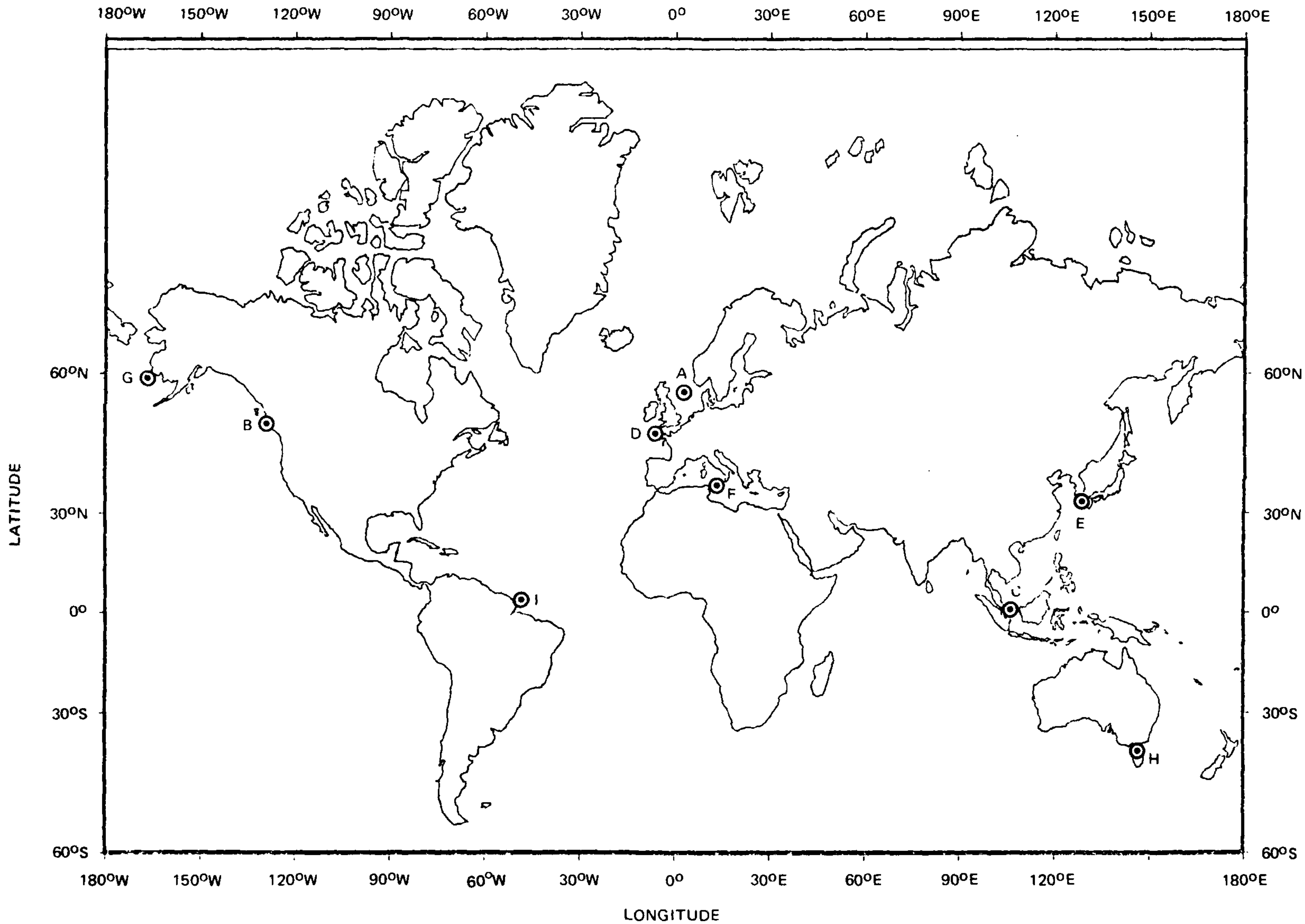


Figure 2.1. Locations of the shallow water sites.

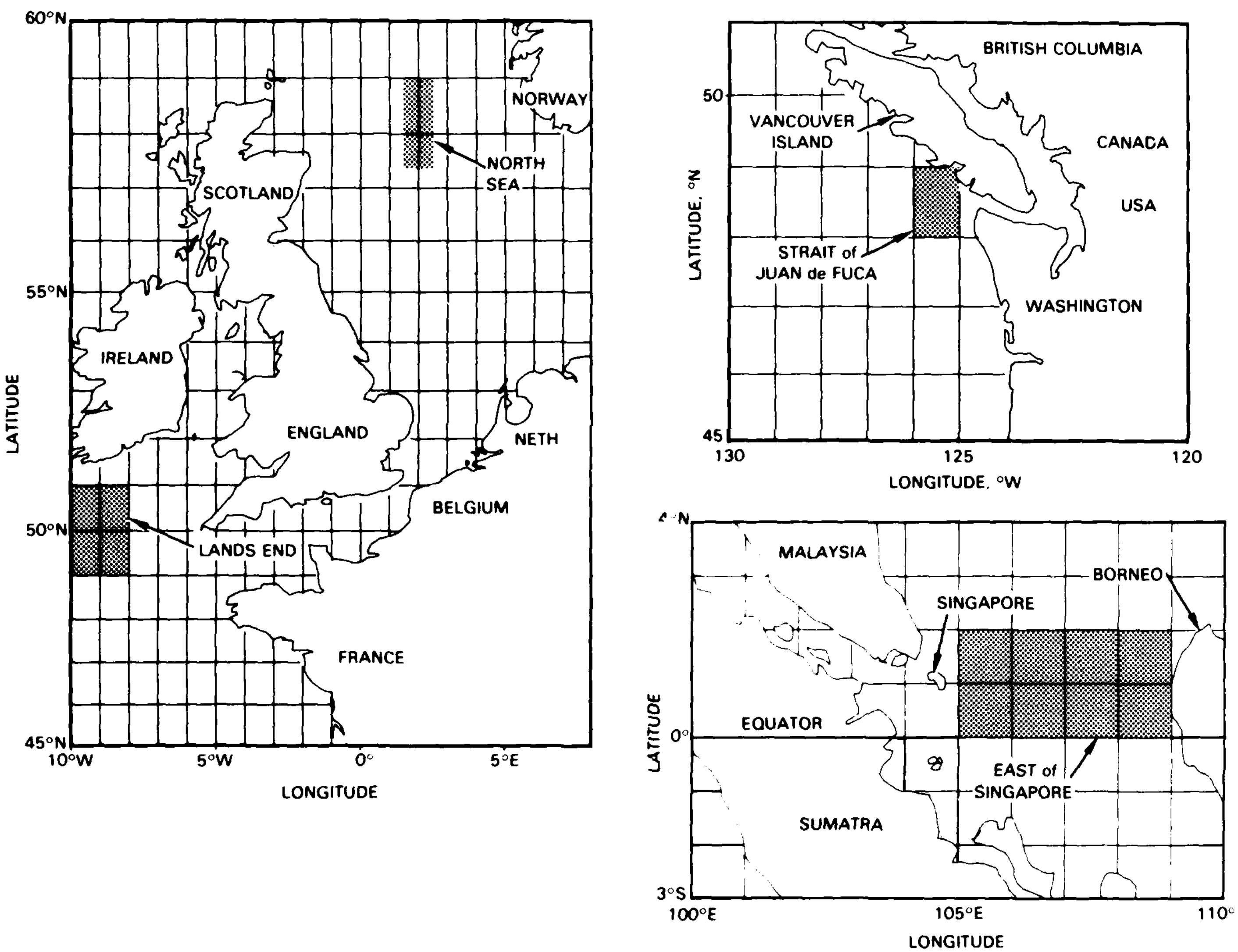


Figure 2.2. Location and surrounding areas of the shallow water sites.

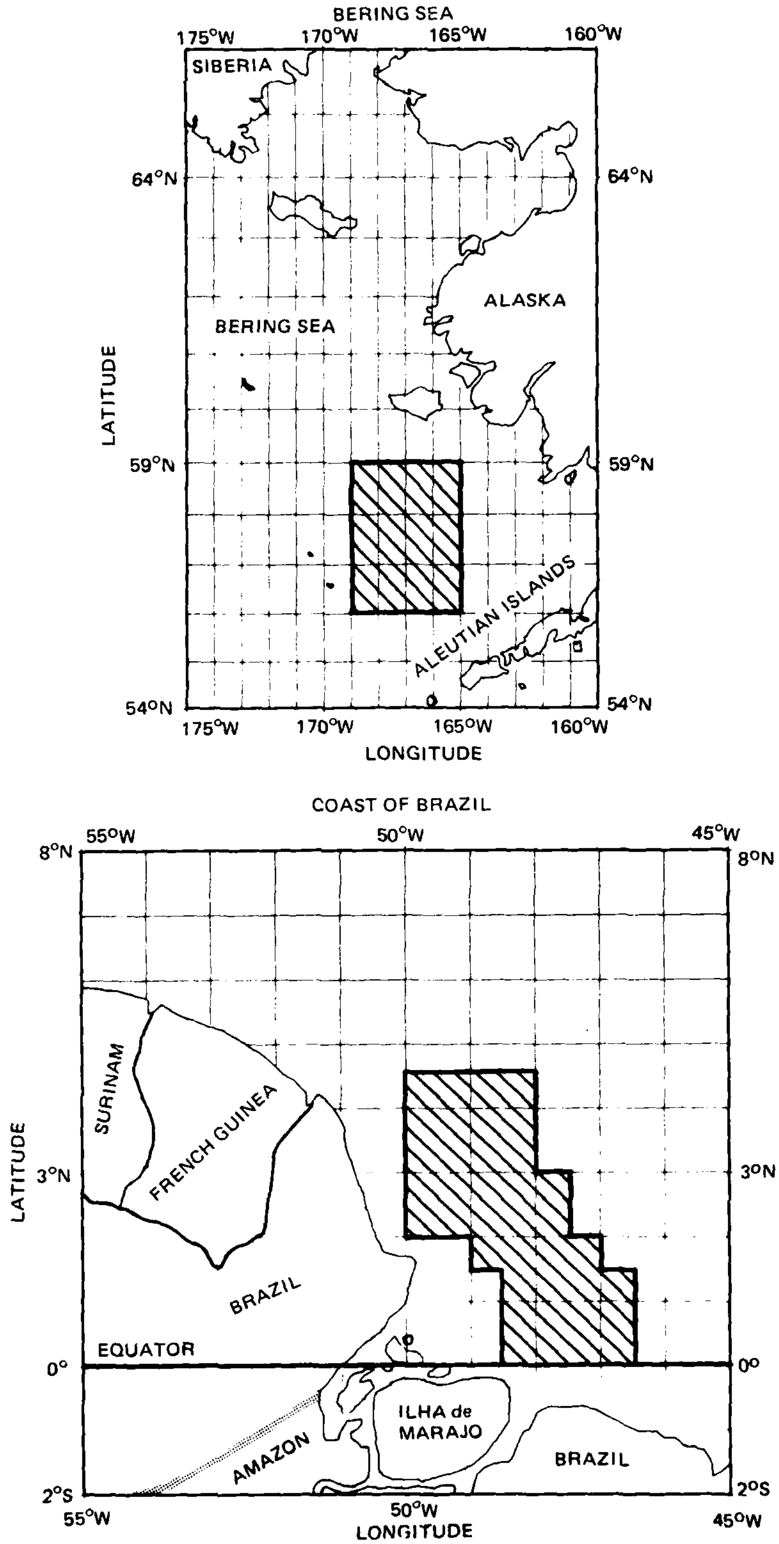


Figure 2.2. Location and surrounding areas of the shallow water sites (continued).

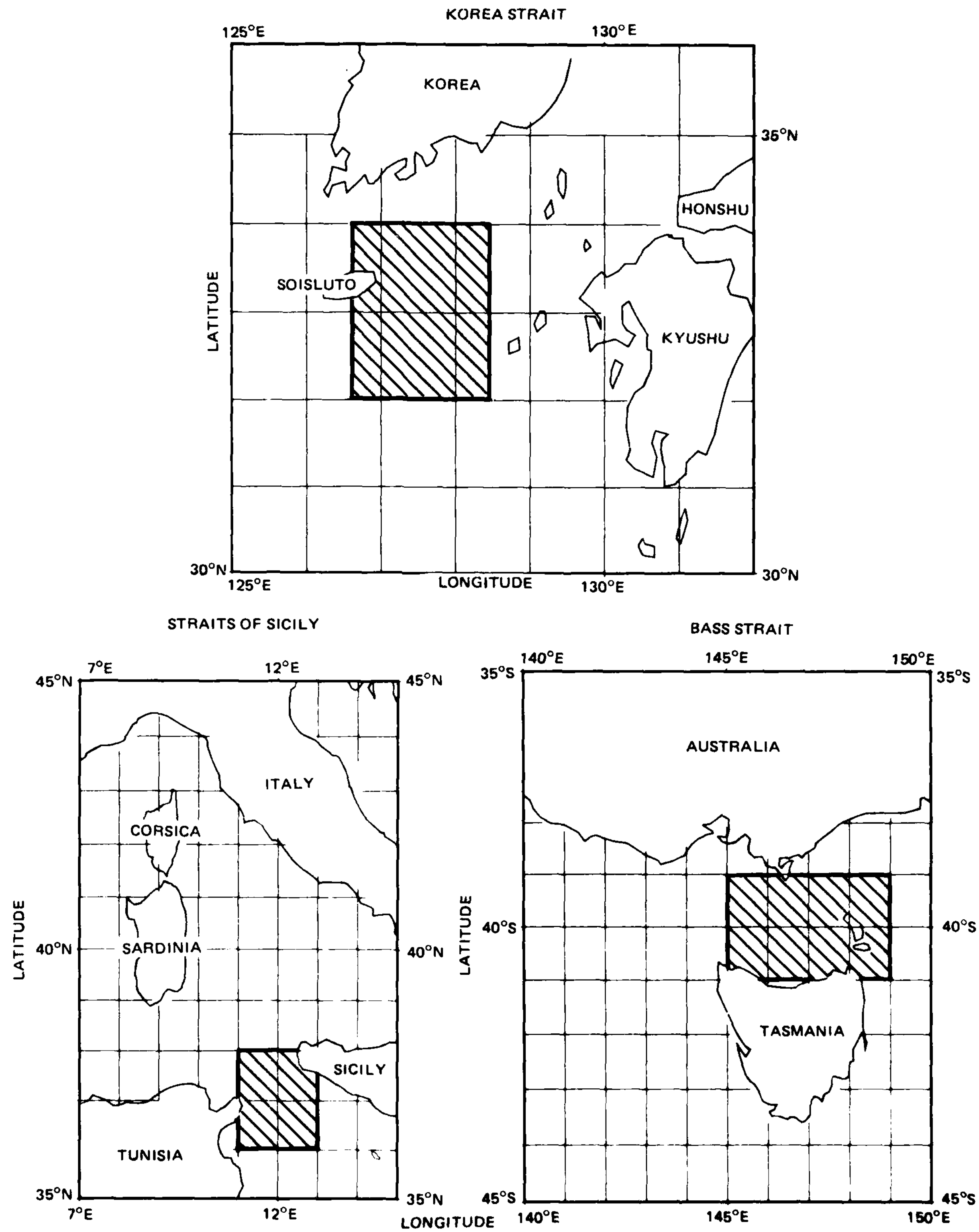


Figure 2.2. Location and surrounding areas of the shallow water sites (continued).

Some profile editing proved necessary to remove redundant sampling in those instances where repeated observations were made at the source location and time. For example, at the Strait of Juan de Fuca site there were two periods of 24 to 48 hours where Nansen casts had been taken each hour. These were replaced by "typical" profiles. This removed possible bias for statistical analyses. Also, in the Korea Strait data set, a large number of casts were taken in 1943. Those were edited out as a separate set. An occasional obviously bad profile was also removed.

Detailed discussion of the selected shallow water environments and details of the computerized methods of the statistical approach to classification and tabulation of profiles and profile gradients are given in the Appendix.

2.2.2 Characteristic Profile Selection

Extreme complexity and variability of sound speed profile shapes were observed in the shallow water data samples, particularly in those from the spring and fall seasons. Procedures established to select a representative sound speed profile for deep ocean environments did not give meaningful results for the shallow water data. Because the gradient of the vertical sound speed structure is important to acoustical propagation, analytical procedures were developed to segregate profile types based on the vertical gradient. From these subsets, representative profiles can be selected and acoustic results evaluated on the probability of occurrence of selected profile types. For this study, profiles were objectively grouped as positive or non-positive gradient profiles with gradient values and percentages of occurrence tabulated.

To classify single profiles as surface duct (positive gradient) or downward refracting (non-positive gradient) a new definition was required. This definition should be based on the expected effect of the overall profile shape on the primary mode of acoustic propagation and must remain relatively simple to apply to all shallow water environments. The basic definition chosen for this analysis will classify a profile as positive if the depth of the absolute maximum observed sound speed value (MAX Z) is greater than 10 meters and negative (non-positive) if the absolute maximum is observed within 10 m of the surface. Thus a large number of possible profile shapes can be grouped together in either category. As a first order profile-type separator for an assumed near surface sound source, this sorting approach works well.

Examples of possible positive gradient and non-positive (negative) gradient profile types are shown in Figure 2.3. Profiles a through d are positive gradient profiles while e through h are negative (non-positive) gradient profile types. Throughout the remainder of this report the two classes of profiles will be referred to as positive and non-positive gradient profiles. Also, positive gradient profiles are regarded as surface ducted profiles.

Two methods of computerized statistical tabulation for the vertical sound speed gradients were used. Gradients were computed in units of meters/second per meter (or inverse seconds). The Appendix gives examples with tabulated results. The first approach produced a tabular listing, by season, of the number of positive and non-positive gradients observed in the data set from the surface to each successive standard depth and provided statistics on gradient strengths. The tables indicated if the overall gradients were positive or non-positive and some measure of correlation between gradient and depth of observation.

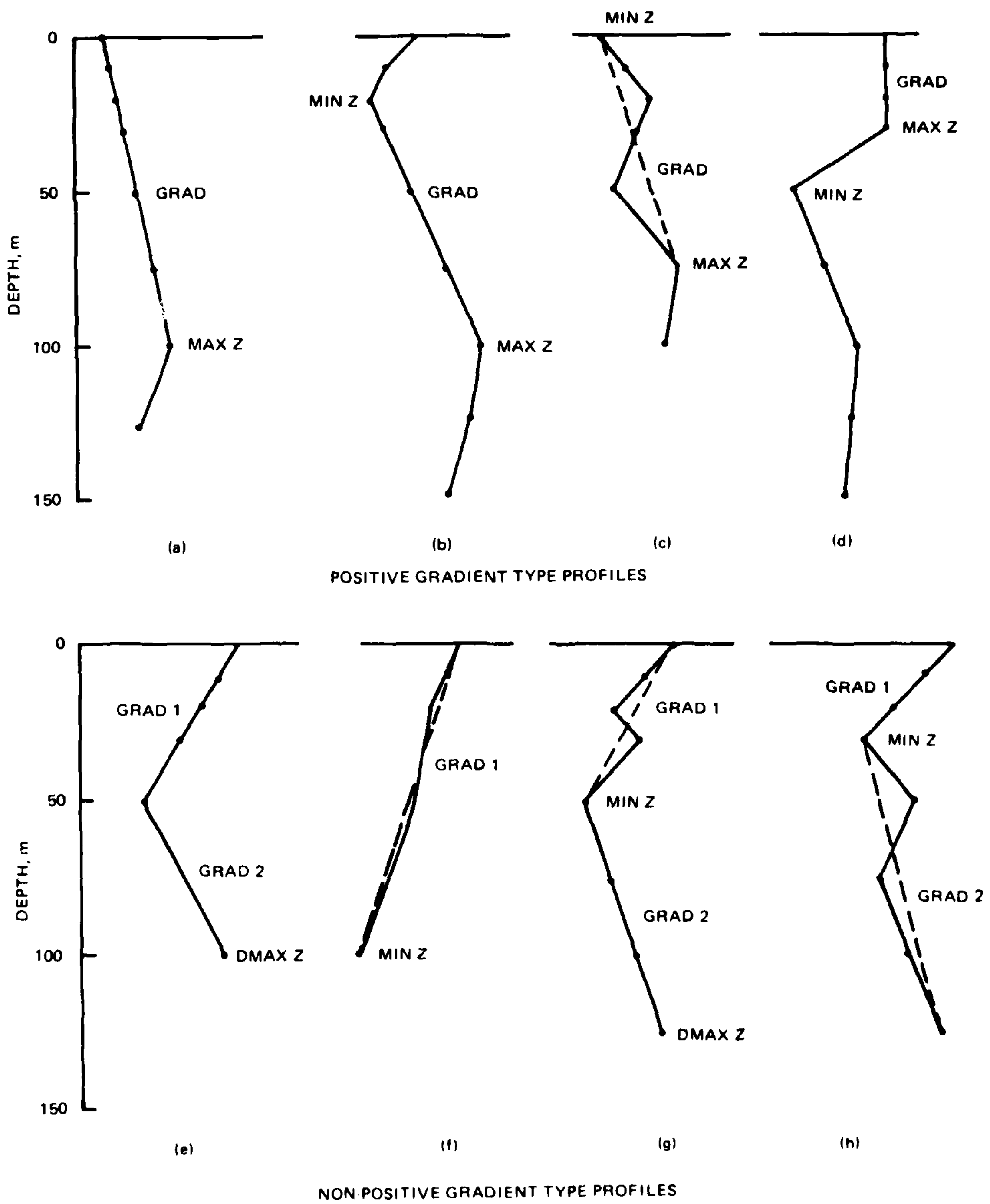


Figure 2.3. Types of idealized shallow water sound speed profiles.

The second statistical approach preserves the identity of each profile while providing a measure of the distribution of positive and non-positive sound speed profiles. Each profile is classified according to the above definition. See also Figure 2.3.

Additional statistics are computed to provide information on the strength of the observed gradients. For positive profiles the gradient from the absolute sound speed maximum to the shallower sound speed minimum is computed and tabulated. For non-positive profiles, the gradient from the near surface maximum to the deeper absolute minimum is computed. If the profile has a deeper positive gradient leg below the absolute minimum, this value is computed also. With this statistical summary, we could determine how many profile types are necessary to adequately represent the particular shallow water site and season. With the aid of the gradient strength and depth information, suitable representative profiles may be selected from the individual data subsets for acoustic model inputs.

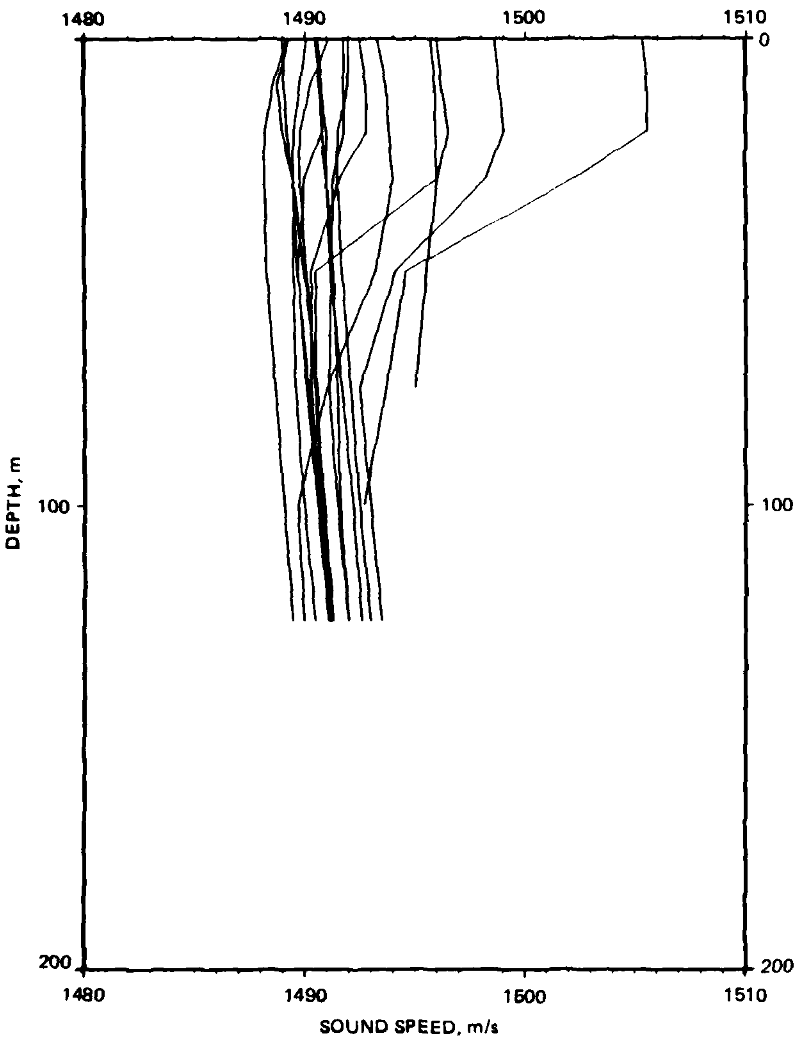
To illustrate the division of a sample of sound speed profiles by the definition illustrated in Figure 2.3, the profiles from the Lands End site, spring season, were separated and replotted in Figure 2.4. Figure 2.4a shows the positive-gradient profiles while Figure 2.4b shows the non-positive gradient profiles.

2.3 Normal Mode Calculations

Propagation loss calculations were made following procedures given by D. F. Gordon in Reference 7. The normal mode program utilizes a multilayer (up to 12 layers) model of the shallow water channel. The bottom sediment layers are modeled in the same manner as the layers in the water. Thus a liquid bottom is assumed and the effect of shear waves is ignored. Each layer is characterized by five quantities: the sound speed at the top and bottom of the layer, the sound speed gradient at the top of the layer, the compressional wave absorption (equal to zero in the water) at the top and the bottom of the layer and the density which is assumed constant in the layer. The absorption loss in the water is computed from Thorp's equation (Reference 8) and is added to the propagation loss at the end of the computation. The model can handle discontinuities in sound speed between water and sediment or between sediment layers or between sediment and rock.

Propagation loss as a function of frequency was calculated for a discrete frequency range of 50 Hz to 4 kHz. The source depth was held constant at 25 meters and the receiver depth was optimized, i.e., adjusted for maximum intensity. For example, see Figure 4.4 where propagation loss for 275 and 500 Hz was plotted versus receiver depth for the range of 100 km. The propagation loss was taken to be 75.8 dB and 83.5 dB at 275 and 500 Hz, respectively. A random phase addition of the mode contributions was used in the calculations. A phased mode addition gives large spatial variation and would be difficult to interpret at a given range. The random phase calculations are equivalent to the results which would be obtained from phased mode theory by averaging over a range interval centered at the fixed range.

7. Shallow Water Normal Mode Model with Structured Bottom, D. F. Gordon, Paper IV-B, Shallow Water Mobile Sonar Modeling Symposium, Naval Research Laboratory, 23-25 September 1975.
8. Analytic Description of the Low-Frequency Attenuation Coefficient, W. H. Thorp, J. Acoust. Soc. Am., Vol 42, 1967, p. 270 (L).



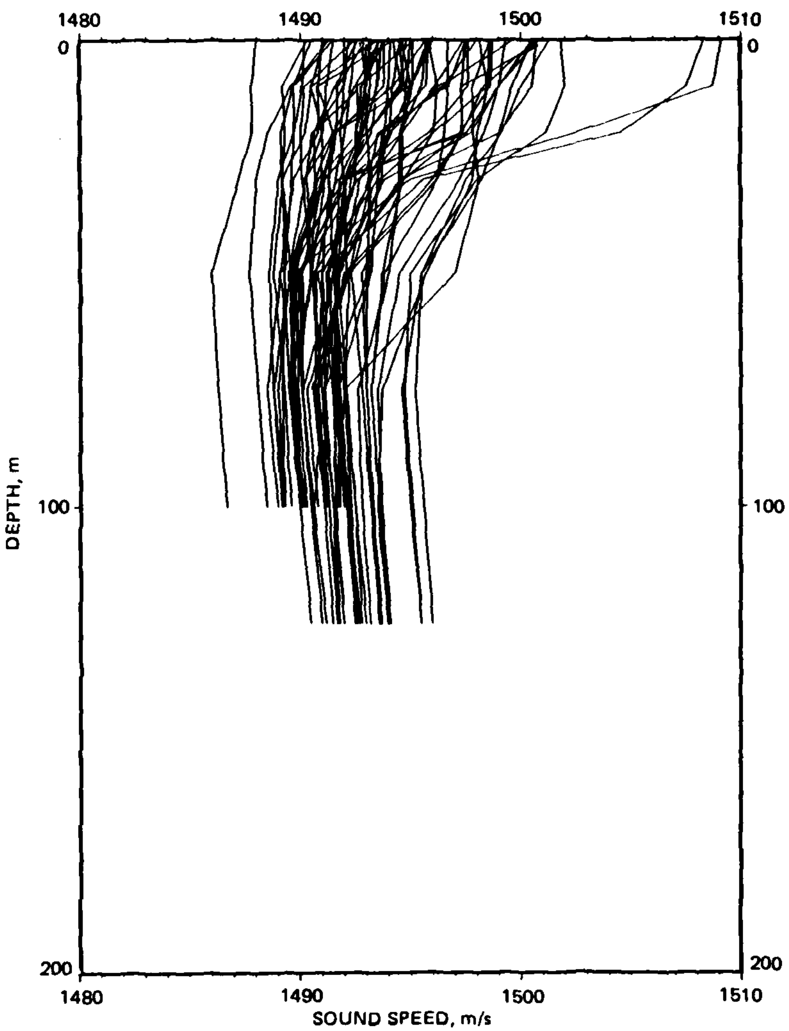


Figure 2.4a. Examples of positive gradient profiles: Lands End -- spring.

Figure 2.4b. Examples of *non*-positive gradient profiles: Lands End -- spring.

Propagation loss was then plotted as a function of frequency for ranges of 50, 100 and 150 km. The curves show a minimum loss over a frequency range which is sometimes relatively broad. This indicates the optimum frequency of propagation for the conditions of the sound speed profile and the sediment properties of that site and season. For the case of downward refraction, the optimum propagation occurs at a relatively low frequency, at which a mode exists with small bottom reflection loss and a large loop length. The loop length is the dominant factor. If a surface duct exists, propagation in the duct usually overpowers the bottom reflected propagation. In this case, the optimum frequency of propagation occurs when the surface duct is optimized or where the propagation is driven by one or two modes. The frequency is usually much higher.

3. SITE DATA

This section contains the physical descriptions and a summary of the profile statistics for each site. The representative sound speed profiles and bottom sediment characteristics are given for six of the nine areas. Propagation loss calculations were made for those areas.

3.1 North Sea

The local area at the North Sea site, 58.5°–59°N, 1.5°–2.5°E, is shown on the bathymetric chart in Figure 3.1. The area generally south of the 100 m contour is a flat plateau at water depths between 80 and 100 m. In the area above 57.5°N, the sea floor slopes into a flat basin below 150 m (maximum depth about 159 m). To the north and west, the sea floor is more hilly and gradually deepens to the north above 59°N. At the site, the average depth is 100 m.

Figure 3.2 shows characteristic sound speed profiles for the North Sea site. The winter profile has positive gradients from surface to bottom as do all of the representative winter profiles (for each site). The "intermediate" profile was of a type observed in about 20 percent of the spring profile samples and occasionally in the summer profiles. The summer profile has small negative gradients to 20 m. Table 3.1 summarizes the North Sea sound speed profiles and shows the relative numbers of profiles that were classified as positive or non-positive gradient profiles.

Season	Total	Positive Gradient, #	Positive Gradient, %
Fall	89	82	92.1
Winter	109	103	94.5
Totals	198	185	93.3
Spring	193	64	33.2
Summer	173	42	24.2
Totals	366	106	28.7

Table 3.1. North Sea profiles.

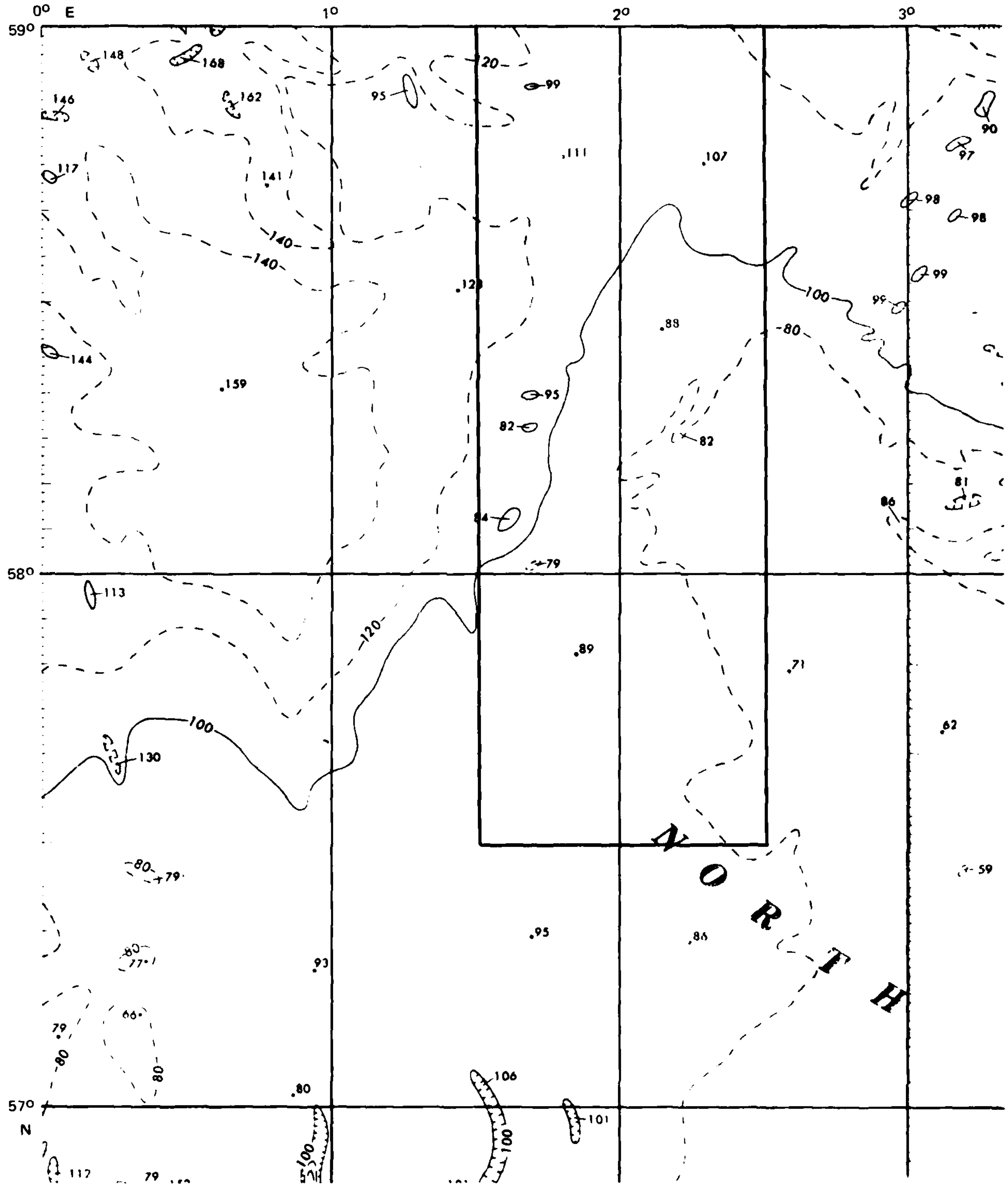


Figure 3.1. Chart of local area — North Sea.

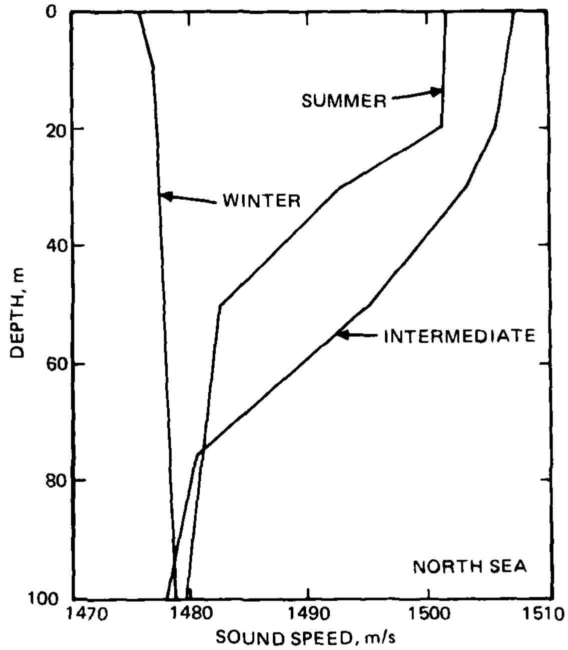


Figure 3.2. Characteristic sound speed profiles found at the North Sea site.

From the table, the probability of encountering a surface duct environment is 93.3 percent in the fall or winter seasons, while in the spring or summer the occurrence of surface ducts is only 28.7 percent.

The properties of the sediments are given in Table 3.2. R is the ratio of the surface sediment sound velocity to that of the bottom water (for all profiles in that area) and the sound velocity given in the sediments is greater by that ratio for the winter sound speed profile. The attenuation α is in units of (dB/km)/Hz and thus must be multiplied by the frequency to obtain absorption.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 1.19		
1	Fine sand	2	Sfc	1760	0.47	2.05
			2-	1778	0.42	2.05
2	Mudstone	2000	2+	1700	0.12	1.74
			1000	2000	0.07	2.1
			2002-	2300	0.02	2.2
3	Sandstone		2002+	2540	0.02	2.2

Table 3.2. Sediments at the North Sea site.

The generalized stratigraphy to about 2000 m is as indicated in Table 3.2. It is a 2 m layer of sand overlying about 2000 m of stiff, hard clay and mudstone, which in turn overlies an oil-producing sandstone layer considered to be the acoustic basement.

3.2 Strait of Juan de Fuca

The local area of this site, 48°-49°N, 125°-126°W, is on the continental shelf west of the Strait of Juan de Fuca (see Figure 3.3). The shallow La Perouse Bank is in the upper part of the area while deeper canyon areas are to the south and southwest. The data sample contained sound speed profiles with maximum depths from 50 m to 200 m. The average water depth at the site was taken to be 130 m. Figure 3.4 shows characteristic sound speed profiles for this site; 75 percent of the fall profiles were of the positive gradient type. Thus, a representative fall profile is shown with a surface duct to 30 m.

Table 3.3 summarizes the sound speed profiles and gives the relative number of positive versus non-positive gradient profiles.

Season	Total	Positive Gradient, #	Positive Gradient, %
Winter	42	41	98
Spring	44	15	34
Summer	22	0	0
Fall	44	11	75
Fall + Winter	86	74	86
Spring + Summer	66	15	23

Table 3.3. Strait of Juan de Fuca sound speed profiles.

The occurrence of surface ducts in this sample was only 23 percent in the spring or summer (April to September) while the probability of encountering a surface duct in the period of October-March was increased to 86%.

The properties of the sediments for this site are given in Table 3.4. The location of the geoacoustic model is 30 nmi west of the entrance to the Strait of Juan de Fuca. The area is a relatively flat part of the continental shelf. Acoustic reflection records and coring data indicate 40 to 50 m of sandy mud or muddy sand overlie thick, folded and eroded sedimentary rocks.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R* = 1.03		
1	Sand - silt		Sfc	1525	0.15	1.61
	clay	47	47-	1586	0.16	1.67
2	Sedimentary		47+	3000	0.10	2.30

*R = the ratio of the surface sediment sound velocity to the speed of sound in the bottom water.

Table 3.4. Sediments at the Strait of Juan de Fuca site.

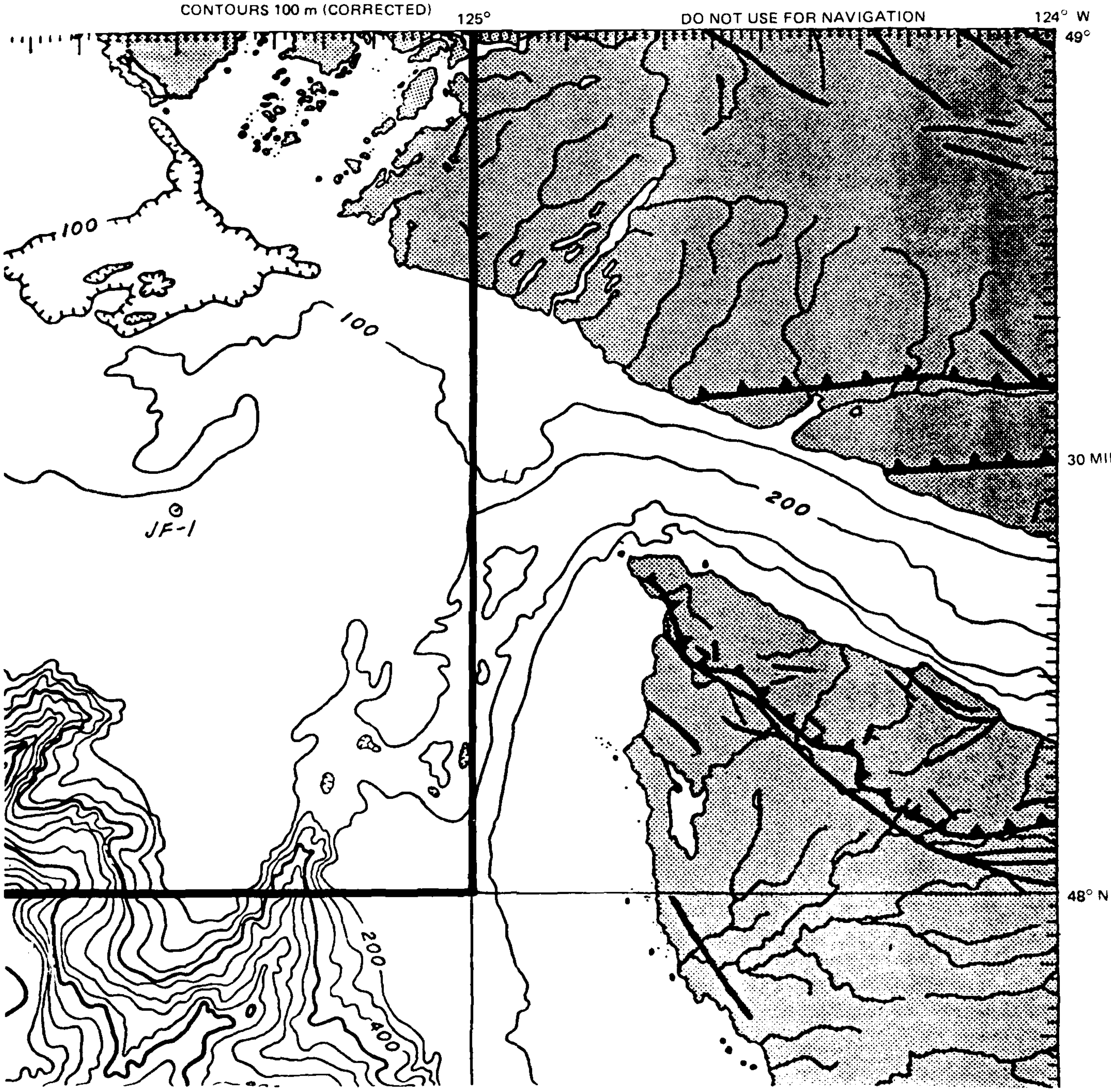


Figure 3.3. Chart of local area   Strait of Juan de Fuca.

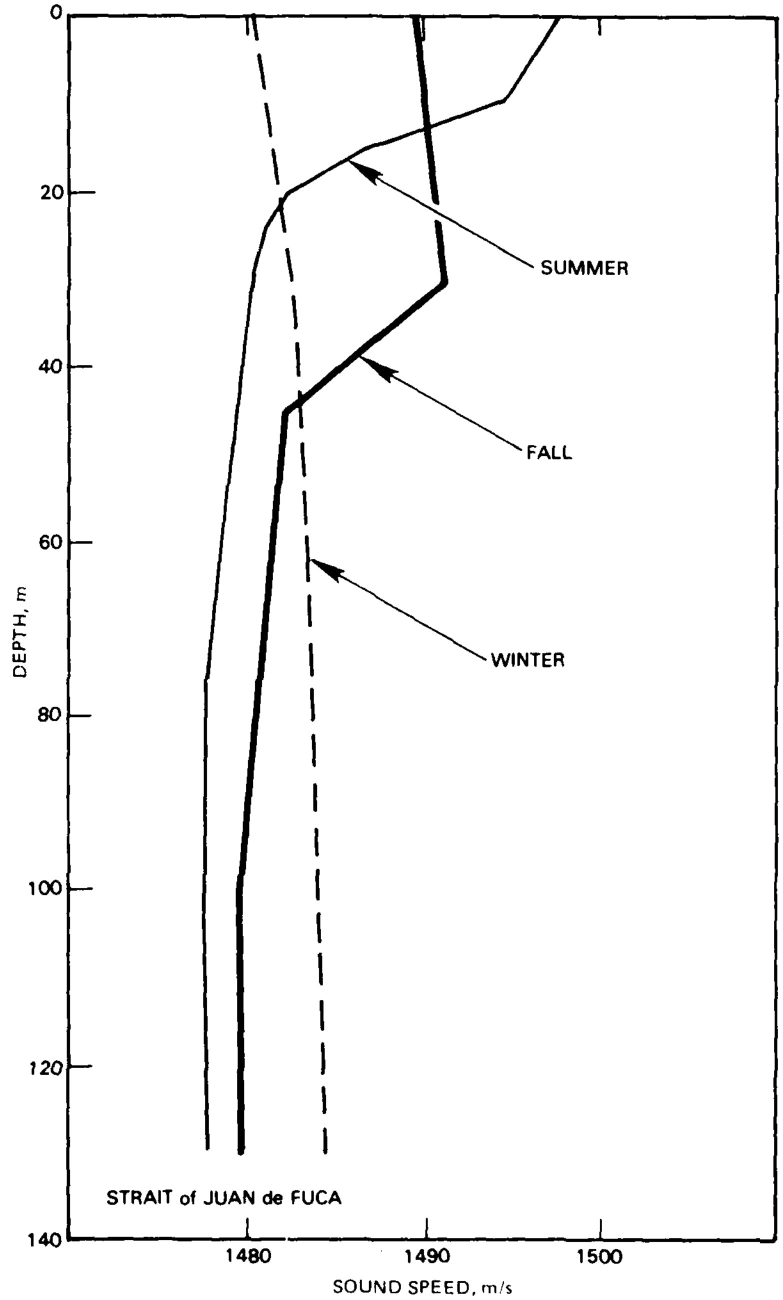


Figure 3.4. Characteristic sound speed profiles found at the site in the Strait of Juan de Fuca.

3.3 East of Singapore

The local area at the site East of Singapore, 0°–2°N, 105°–109°E, is located on the chart in Figure 3.5. The site lies on the Sunda continental shelf, east-southeast of Singapore and west of the island of Borneo. This is an example of an equatorial shallow water environment which also is isolated from open ocean influences. Water depths are quite shallow, varying from about 25 m to 75 m. The mean depth is taken to be 50 m. Few Nansen cast data were available and the original area was expanded from 0°–1°N, 106°–107°E. Also the data set was supplemented with a large percentage of XBT data.

Figure 3.6 gives representative profiles for the two seasons. The months October through March were processed as winter and April through September, as summer. From Table 3.5, it is seen that 82.5 percent and 60 percent of the winter and summer profiles, respectively, were classified as positive gradient profiles.

The sediment properties for this site* are given in Table 3.6. The area is covered by a 70–80 m layer of mud (silt-clay) overlying a harder sand-silt-clay layer about 110 to 120 m thick. The underlying acoustic basement (layer three) is probably basalt. The whole area is relatively flat except for some deeper areas near islands.

Season	Total	Positive Gradient, #	Positive Gradient, %
Winter	40	33	82.5
Summer	35	21	60.0
Totals	75	54	72.0

Table 3.5. Summary of sound speed profiles for the site East of Singapore.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 0.99		
			Sfc	1523	.06	1.45
1	Silt-clay	78	78-	1617	.07	1.55
2	Sand-silt	113	78+	1830	.07	1.89
	clay		191-	1943	.08	2.02
3	Basalt		191+	4200	.03	2.37

Table 3.6. Sediment properties of the site East of Singapore.

*The geoacoustic model was originally constructed for the one-degree square, 0°–1°N, 106°–107°E but is considered valid over the expanded area.

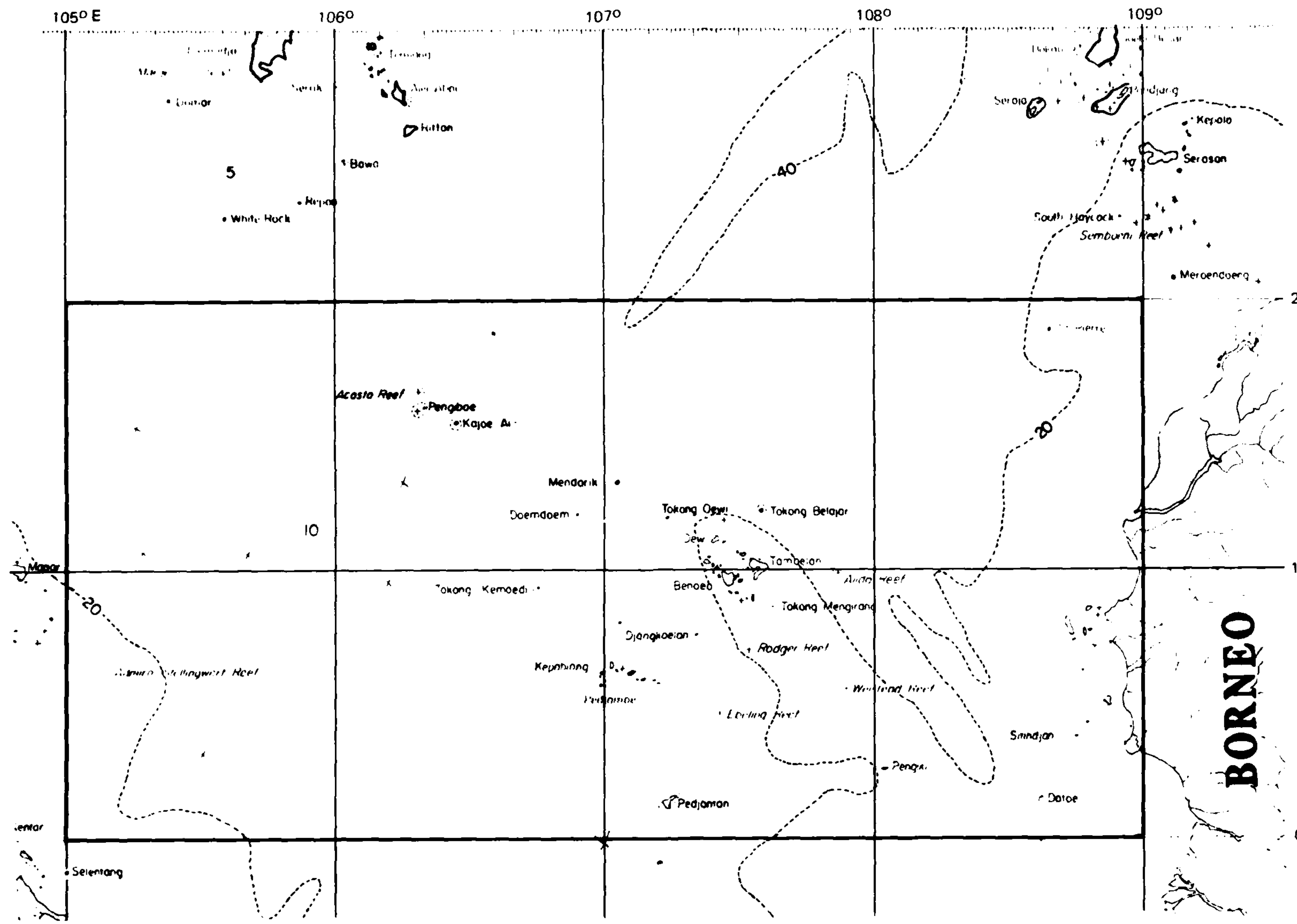


Figure 3.5. Chart of local area – East of Singapore.

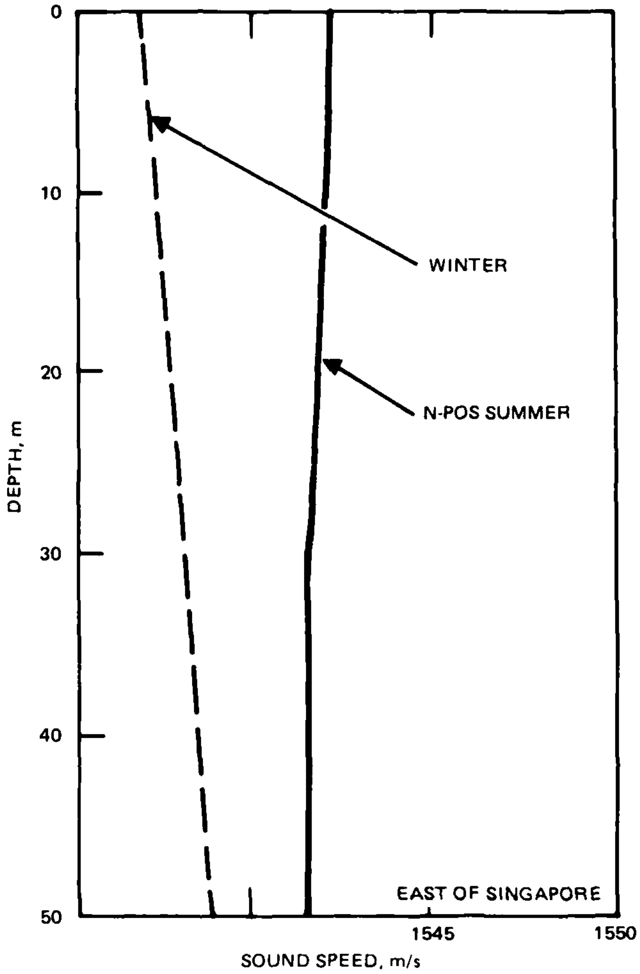


Figure 3.6. Characteristic winter and summer sound speed profiles for East of Singapore site.

3.4 Lands End

The Lands End site is located on the continental shelf, southwest of England. The local area, 49°-51°N, 8°-10°W, is shown in Figure 3.7. This site represents a high latitude location exposed to the influence of the open ocean circulation in contrast to the relatively more isolated North Sea site. Water depths of the sound speed profile data sample varied from 80 to 151 m. Representative winter and summer sound speed profiles are shown in Figure 3.8 to the average depth of 125 m. A summary of the sound speed data set is given in Table 3.7. Ninety-eight percent of the fall and winter profiles and 23 percent of the spring and summer profiles were classified as positive gradient profiles.

Properties of the sediments at this site are given in Table 3.8. The sediment is sand with undulations up to 25 m high. An intermediate layer of mudstone overlies the acoustic basement of sedimentary rock at about 320 m deep.

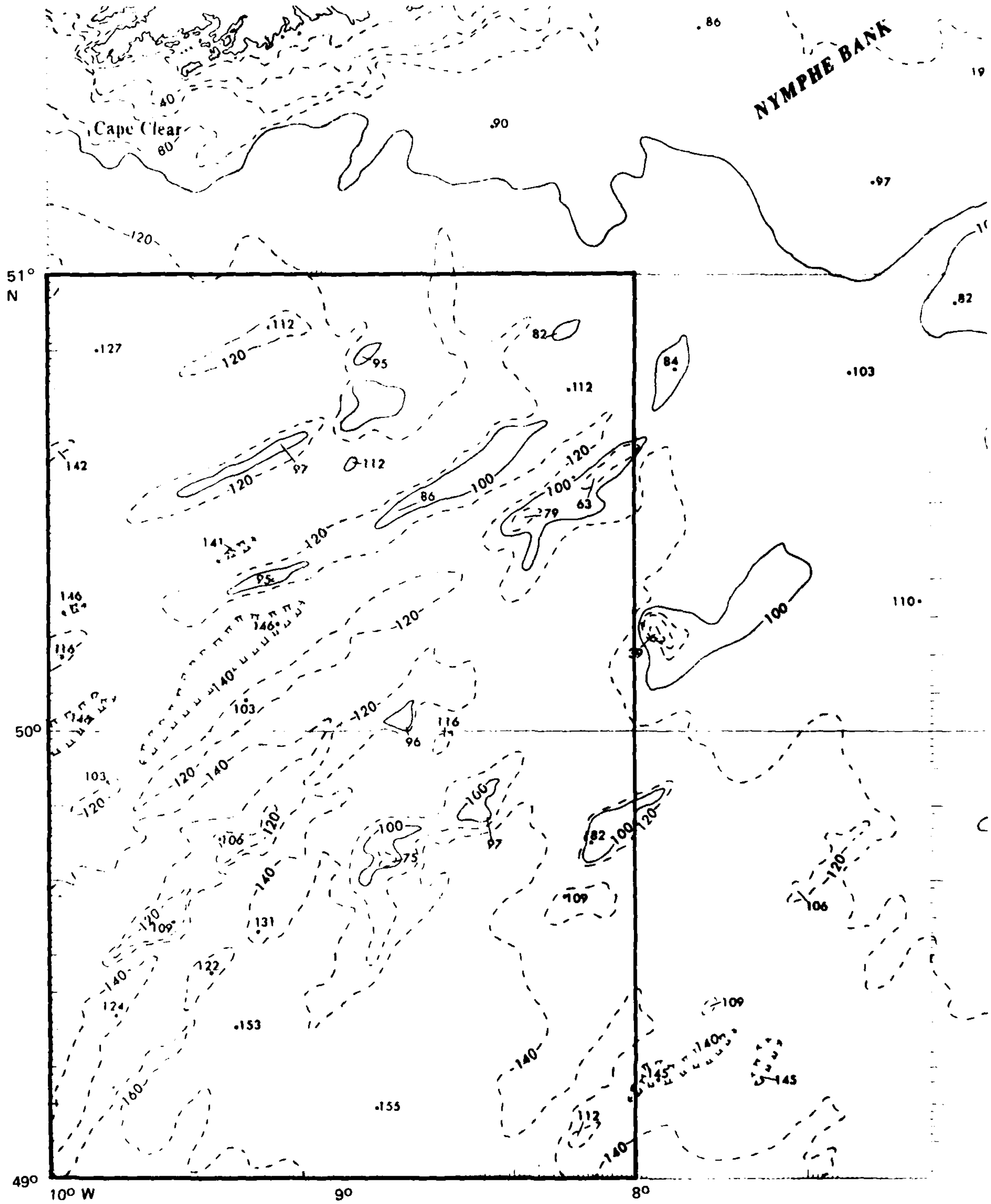


Figure 3.7. Chart of local area Lands End.

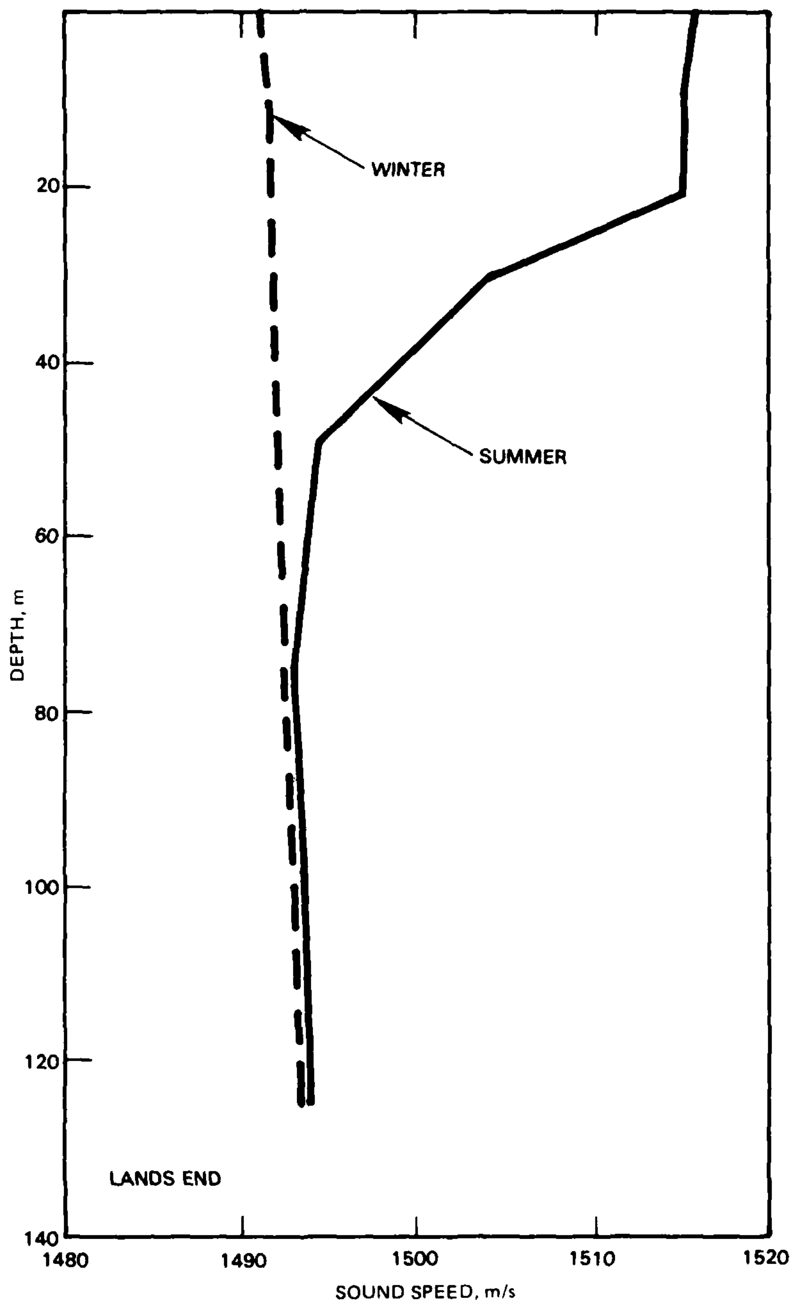


Figure 3.8. Characteristic winter and summer sound speed profiles for the Lands End site.

Season	Total	Positive Gradient, #	Positive Gradient, %
Fall	49	47	96
Winter	50	50	100
Totals	99	97	98
Spring	80	16	20
Summer	75	20	27
Totals	155	36	23

Table 3.7. Lands End profiles.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 1.116		
			Sfc	1670	0.50	1.85
1	Silt-clay	30	5	1710	0.38	
			10	1730	0.34	
			20	1747	0.30	
			30-	1757	0.28	1.85
2	Mudstone	290	30+	1800	0.03	2.0
			320-	2090	0.02	2.12
3	Sedimentary rock		320+	4360	0.01	2.64

Table 3.8 Sediment properties of the Lands End site.

3.5 Korea Strait

The area chosen for the Korea Strait site was a two-degree square, 32°–34°N, 126.5°–128.5°E, which includes the locations of the 1966, Fasor Station OAK and the SHAREM 26 trials (1978) (Reference 9). The area and site are shown on the bathymetry chart in Figure 3.9.

A summary of the sound speed profile data set is given in Table 3.9. This data set is quite large with over 500 profiles after excluding those from 1943. The positive gradient profiles are 85 percent for fall and winter and 27.6 percent for spring and summer.

Representative sound speed profiles for the Korea Strait site are shown in Figure 3.10 to the average water depth of 128 m. The winter profile has a small (average .02) positive gradient from surface to bottom while the summer profile has relative strong negative gradients below 10 m depth.

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9. Reference available to qualified requestors.

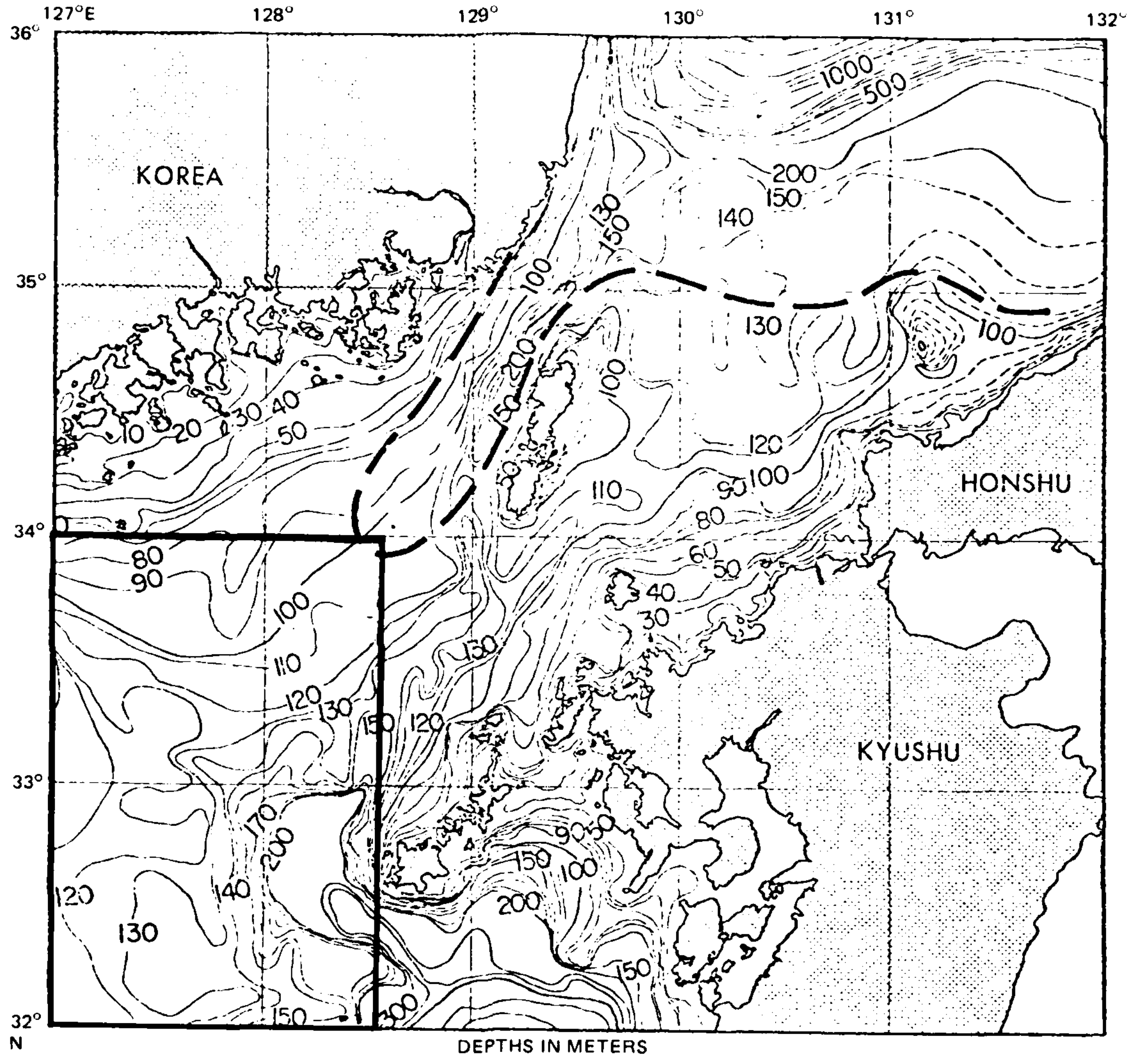

Figure 3.9. Chart of local area — Korea Strait.

Season	Total	Positive Gradient, #	Positive Gradient, %
Fall	82	64	78.0
Winter	115	103	89.6
Totals	197	167	85.0
Spring	140	41	29.3
Summer	172	45	26.2
Totals	312	86	27.6

Table 3.9. Korea Strait sound speed profiles.

Sediment properties for this site are given in Table 3.10. This geoacoustic model was constructed by Dr. E. L. Hamilton of NOSC, Code 5031, from qualitative information about the composition and layering of the sediments (Reference 10). The sea floor at the site is smooth and flat. The surface sediment is a fine sand. The sediment of mud (silt-clay) over the acoustic basement (assumed to be basalt) in the general area may vary between about 400 and 2000 m and is modeled at 1000 m thickness here. The fine sand surface sediments (modeled here to be 3 m thick) do not extend over the entire Korea Strait (Reference 11). A geoacoustic model at a location in the northeastern part of the Strait will probably be nearly the same as Table 3.10 without the fine sand surface layer.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 1.68		
			Sfc	1762	0.5	1.93
1	Fine sand	3	3-	1790	0.4	1.93
2	Terrigeneous	1000	3+	1510	0.10	1.53
	Mud		100	1633	0.11	1.66
	(silt-clay);		200	1743	0.12	1.78
	turbidities		400	1929	0.14	1.99
			600	2081	0.12	2.14
			800	2211	0.10	2.35
			1000	2330	0.09	2.31
3	Basalt	1000+	4100	2000	0.03	2.33

Table 3.10. Sediment properties at the Korea Strait site.

10. Reference available to qualified requesters.
11. Reference available to qualified requesters.

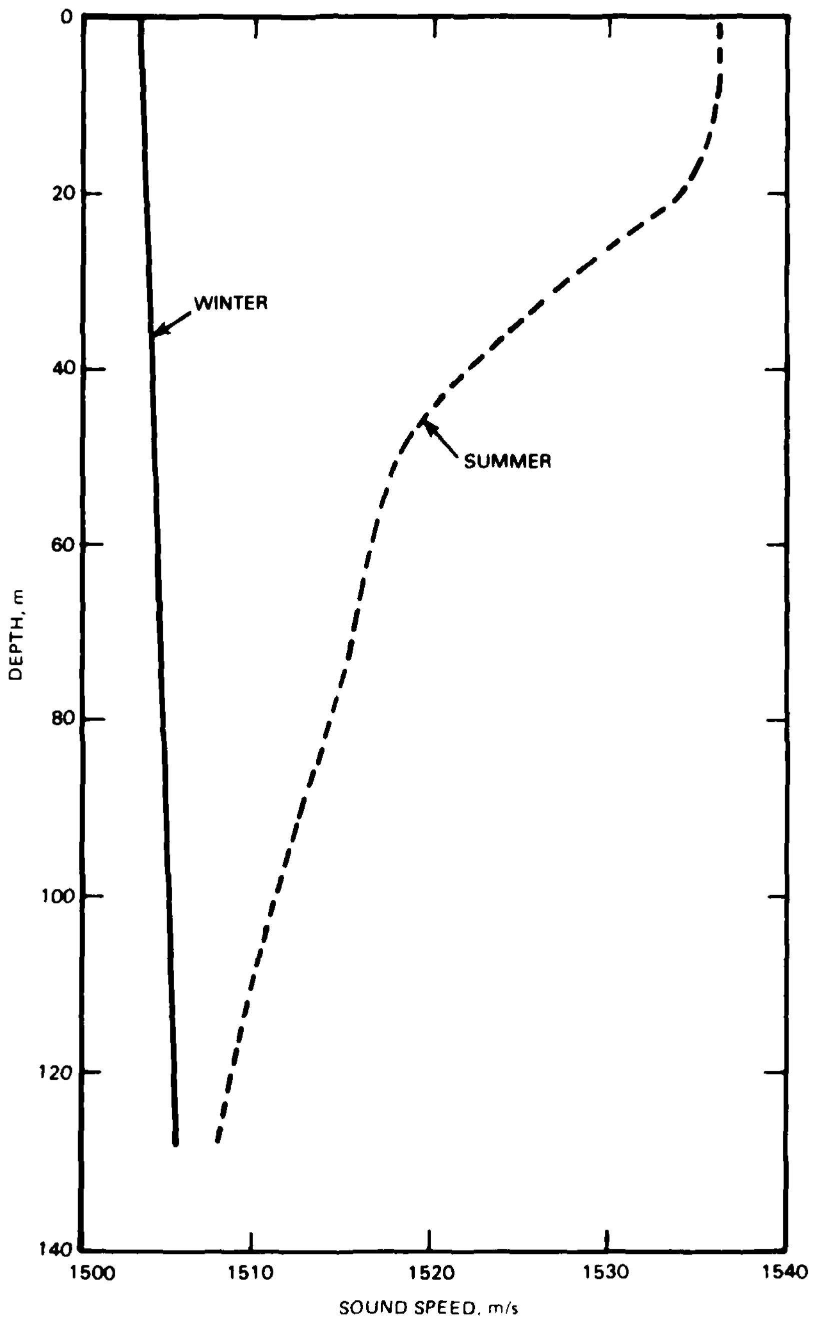

Figure 3.10. Characteristic winter and summer sound speed profiles for the Korea Strait site. The summer profile is an August profile.

3.6 Straits of Sicily

The Straits of Sicily site, 36°–38°N, 11°–13°E, is located on the chart (Reference 12) in Figure 3.11. The straits separate Sicily from Africa and divide the Mediterranean Sea into two basins. The bathymetry is complicated in the central part but simple on the continental shelves along the Sicilian and African coasts. The sea floor of the shelf area is very flat except for a few very shallow banks. In the middle of the straits there is a region of depths greater than 900 m. In the complicated zone between, the depths very between 200 and 900 m.

The data sample from this area contains sound speed profiles to 700 m in depth with about one-third of the sample profiles deeper than 200 m. The representative winter and summer profiles are shown in Figure 3.12. Two bottom depths are considered in our model, 165 m and 500 m. The characteristic deep profiles (500 m) were found to be extensions of the shallower sound speed profiles (150–200 m).

Table 3.11 gives a summary of the sound speed profiles. Although the sampling for fall and winter is not robust, the 98 percent positive gradient profiles found are most likely a true value. The percentage found in spring and summer (10.3) is the average of the two seasons.

The geoacoustic models of the sediments in the Straits of Sicily were taken from Reference 13 and are given in Tables 3.12 and 3.13. The model in Table 3.12 is applicable to water depths shoal of 300 m while the second model (Table 3.13) is applicable in the deeper waters of the straits. Both have an acoustic basement of limestone and chalk although at different depths. The compressional wave attenuation is an order of magnitude greater in the shallow model while the densities differ only slightly

Season	Total	Positive Gradient, #	Positive Gradient, %
Fall	21	20	95.2
Winter	28	28	100.0
Totals	49	48	98.0
Spring	71	4	5.6
Summer	40	6	15.0
Totals	111	10	(10.3)

Table 3.11. Straits of Sicily sound speed profiles.

12. Oceanography of the Straits of Sicily, Thomas D. Allen, Tuncay Akal and Robert Molcard, Proceedings of a conference held at SACLANTCEN on 11-12 April 1972, SACLANT ASW Research Centre, 15 September 1972.
13. Geoacoustic Models for the Straits of Sicily and Sardinia-Tunisia, J. E. Matthews, Ocean Science and Technology Laboratory, Naval Ocean Research and Development Activity (unpublished manuscript).

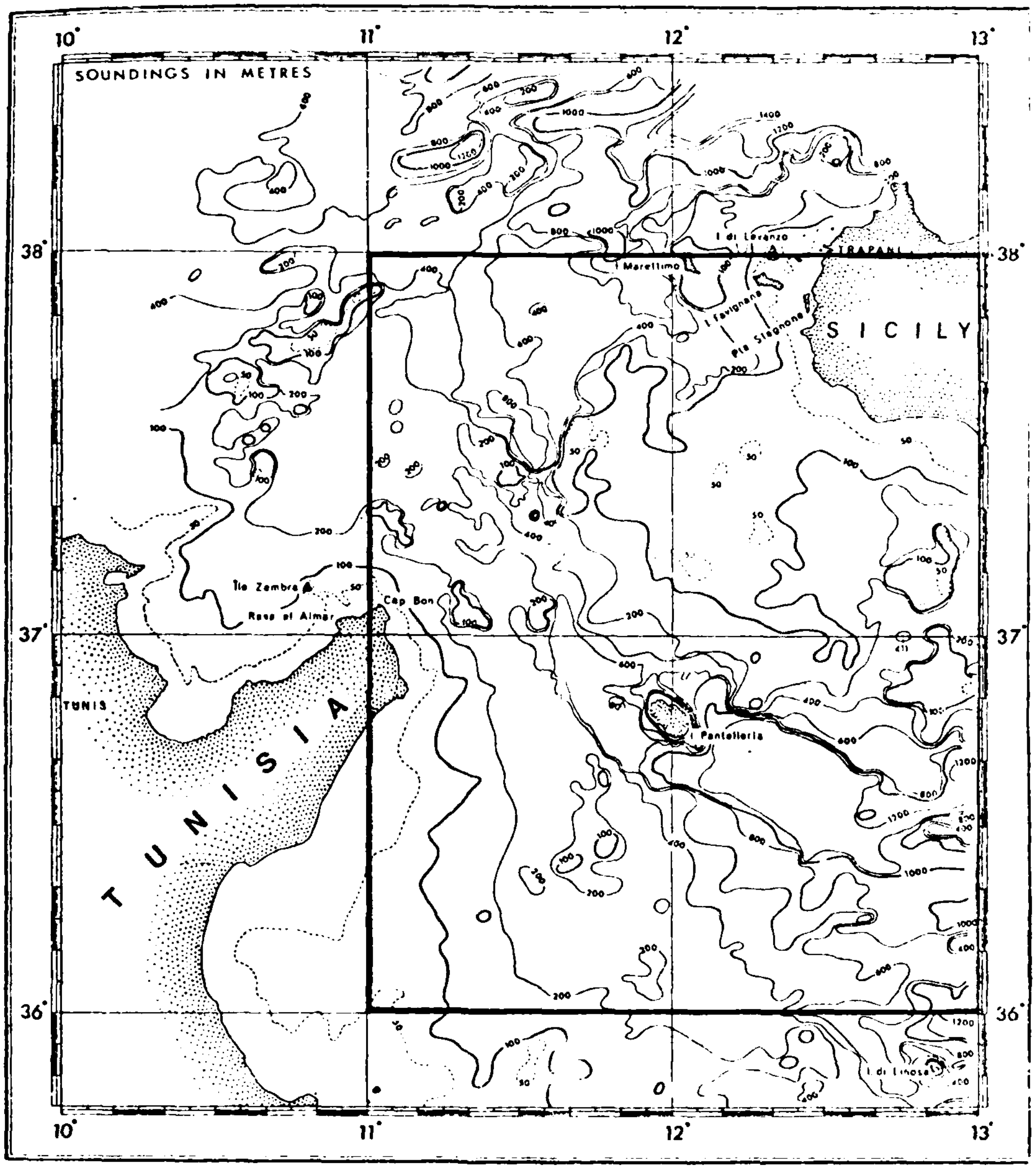

Figure 3.11. Chart of local area — Straits of Sicily.

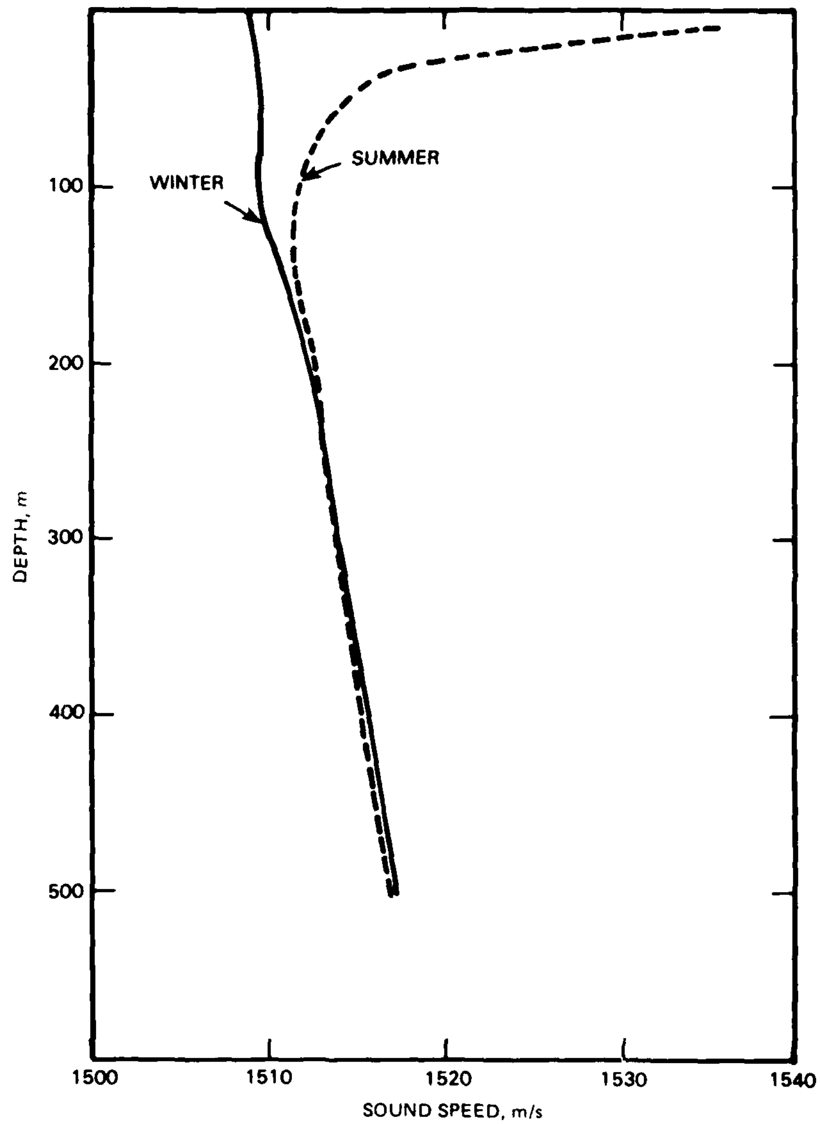

Figure 3.12. Characteristic winter and summer sound speed profiles for the site in the Straits of Sicily.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 1.11		
			Sfc	1678	0.5	1.81
1	Clay, silt and sand	17	2	1695.5	0.445	
			17-	1751	0.312	1.81
2	Limestone and chalk		17+	2200	0.02	2.16

Table 3.12. Straits of Sicily sediments — shallow model*.

*This model is applicable to water depths shoal of 300 meters.

Layer	Material	Thickness, m	Depth, m	Compressional Velocity, m/s	Attenuation, (dB/km)/Hz	Density, g/cm^3
Sea Floor				R = 1.07		
			Sfc	1623	0.027	1.52
1	Clay, silt and silty clay	500	25	1703.5	0.0285	1.55
			50	1721	0.0295	1.57
			100	1739	0.0315	1.65
			200	1757.5	0.034	1.78
			300	1768	0.034	1.88
			400	1776	0.295	1.95
			500-	1782	0.355	2.01
2	Limestone and chalk		500+	2200	0.02	2.16

Table 3.13. Straits of Sicily sediments   deep model.

3.7 Shallow Bering Sea

The Bering Sea has an extended amount of shallow water between 30 m and 100 m in depth. The region chosen for a site is located 56°–59°N, 165°–169°W (see Figure 2.2). The sound speed profiles from this area were mostly between 50 and 100 m in bottom depth. The data sample was divided into two seasons, October–March and April–September. Results are summarized in Table 3.14. The small number of profiles from the winter months is understandable due to the unhospitable weather conditions at that time of year. However, each of those 13 profiles were positive gradient profiles. It is very highly probable, if not 100 percent certain, that surface ducted sound speed profiles will be found in the fall and winter months in the shallow Bering Sea. In contrast, only 13.4 percent positive gradient profiles were found during spring and summer.

Season	Total	Positive Gradient, #	Positive Gradient, %
April-September	194	26	13.4
October-March	13	13	100.0

Table 3.14. Shallow Bering Sea sound speed profiles.

No calculations were made for this area. However, propagation testing has been done here (References 4 and 5) and sediment properties are obtainable. Thus, optimum frequency studies and/or comparisons to propagation loss data will be included in future reports. For this site, as well as the remaining two sites, no detailed bathymetry and sound speed profiles will be included in this report.

3.8 The Bass Strait

The Bass Strait is between Australia and the Island of Tasmania. This is a southern hemisphere site that has sufficient (year round) data in the NODC data banks. The site location is 39°-41°S, 145°-149°E (see Figure 2.2). Water depths varied between 30 and 90 m with an averaged recorded depth (in our data sample) of 66.2 m. There was a high number of positive gradient profiles from each season as seen in Table 3.15.

Season	Total	Positive Gradient, #	Positive Gradient, %
July-September	28	27	96.4
April-June	27	20	74.1
Totals	55	47	85.5
October-December	50	30	60.0
January-March	47	28	59.6
Totals	97	58	60.0

Table 3.15. Bass Strait sound speed profiles.

Even in the spring and summer months (the seasons are reversed in the Southern Latitudes) 60 percent of the sample profiles were of the positive gradient type. During fall and winter, surface ducted propagation is expected about 86 percent of the time, the average of 96 percent in winter and 74 percent in fall.

No propagation loss calculations were made in this location due to the lack of sea floor sediment information.

3.9 North Coast of Brazil

This site is located on the continental shelf off the coast of Brazil. The location is shown in Figure 2.2 and is included within 0-1.5°N, 46.5°-48.5°W; 1.5°-2°N, 47°-49°W; 2°-3°N, 47.5°-50°W and 3°-4°20'N, 48°-50°W. This area was enlarged in this manner to include the shelf area between the mouth of the Amazon River and the Amazon Canyon and to increase the number of sound speed profiles in the data sample.

The majority of the profiles in our sample (60 percent) were less than 75 m in depth while only 19 percent were greater than 100 m deep. Profiles greater than 300 m were edited out of our data sample. Table 3.16 summarizes the sound speed profiles found in this area. A large majority (>85 percent) were positive gradient profiles. All profiles from January–March and 76 percent of the July–December profiles were positive gradient profiles. The few deep profiles had large negative gradients from 100 to 300 m.

Season	Total	Positive Gradient, #	Positive Gradient, %
January–March	20	20	100.
August–December	42	32	76.

Table 3.16. Coast of Brazil sound speed profiles.

No profiles were found in the months of April–July. No propagation loss calculations were made for this area.

3.10 Summary

Table 3.17 summarizes the positive gradient profile data. The winter profiles from each site were predominately of the positive gradient type; eight of the nine sites had 90–100 percent positive gradients. The ninth site, East of Singapore, a low latitude site, showed 82 percent positive gradients in the winter and 71 percent overall. Numbers of positive gradient profiles are low in summer at mid and high (58°) latitudes. The exception is the Bass Strait, 40°S latitude, where 60 percent positive gradients were found in the summer. This may be an isolated case. The small number of sites does not allow any strong statements on the dependence upon latitude. No sites at latitudes above 60° or between 10° and 30° were sampled. The large number of positive gradient profiles found at all sites may be in part due to our definitions. The seasonal dependence at low latitudes (where seasonal effects should be minimal) is somewhat surprising. In general, we sensed that seasonal and latitudinal dependencies in shallow water may be overshadowed by land-mass effects.

Site	Latitude	Positive Gradient Profiles, %	
		Summer	Winter
North Sea	58°N	24	94
Shallow Bering Sea	58°N	13	100
Lands End	50°N	27	100
Strait of Juan de Fuca	49°N	0	98
Bass Strait	40°N	60	96
Straits of Sicily	37°N	15	100
Korea Strait	33°N	26	90
North Coast of Brazil	2°N	76	100
East of Singapore	1°N	60	82

Table 3.17. Summary of positive gradient profiles.

Characteristic or representative profiles were chosen only for those sites where propagation loss calculations were made – the shallow Bering Sea, Bass Strait and North Coast of Brazil are not in this set. The characteristic winter profiles chosen for each site were ones with positive gradients from surface to bottom. Representative summer profiles are of the non-positive gradient (downward refracting) type. Non-positive gradient profiles at East of Singapore occurred in only 40 percent of the summer observations but the characteristic profile was chosen to be non-positive to contrast with the winter profile.

4. ACOUSTIC RESULTS

4.1 Propagation Loss Calculations

4.1.1 North Sea

The computational models for the water column (Table 4.1) and for the sediments (Table 4.2) for the North Sea site are as follows:

Winter		Intermediate		Summer	
Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s
0	1475.8	0	1507	0	1501.5
10	1476.7	30	1503	20	1501.1
100	1478.4	75	1480.5	30	1492.7
		100	1477.6	50	1482.5
				100	1479.5

Table 4.1. Sound speed in the water column.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom, m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)/Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
1	0.0	1760.0	1778.0	8.87	0.47	0.42	2.05
2	2.0	1700.0	2000.0	0.24	0.12	0.07	1.74
3	1000.0	2000.0	2300.0	0.24	0.07	0.02	2.1
4	2000.0	2540.0		-0.1	0.02		2.2

Table 4.2. Sediment parameters used in computations, North Sea site.

Sediment sound speeds given here are for the winter profile. Those for the other seasonal profiles will be adjusted to keep the ratio of surface sediment to bottom water constant (1.19 for the North Sea site). Density in the water was assumed to be 1.03 and a constant value in each sediment layer.

Propagation loss as a function of frequency is shown in Figure 4.1 for the winter profile (positive gradient), Figure 4.2 for the summer profile and Figure 4.3 for the intermediate profile (downward refracting). The source depth was 25 m and the receiver depth was optimized. The concept of optimum receiver depth is illustrated in Figure 4.4. In this figure the depth functions of propagation loss are shown for the frequencies of 150, 300

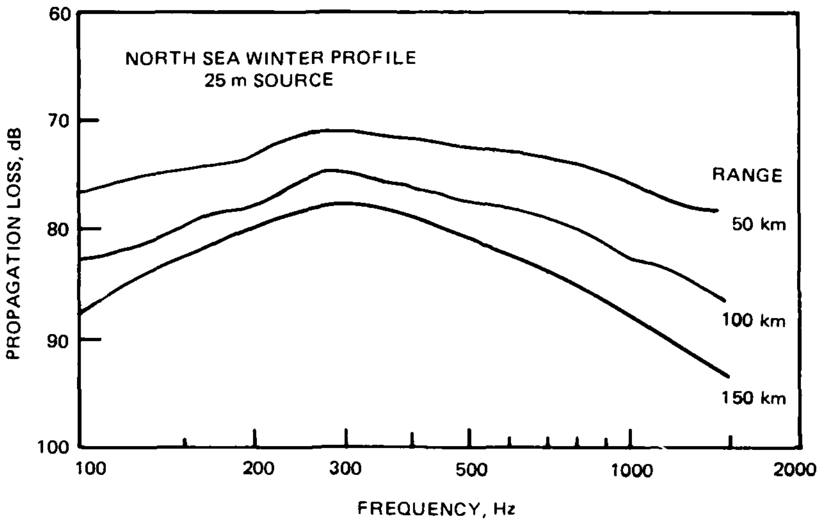

Figure 4.1. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. North Sea winter (positive gradient) profile; source depth 25 m.

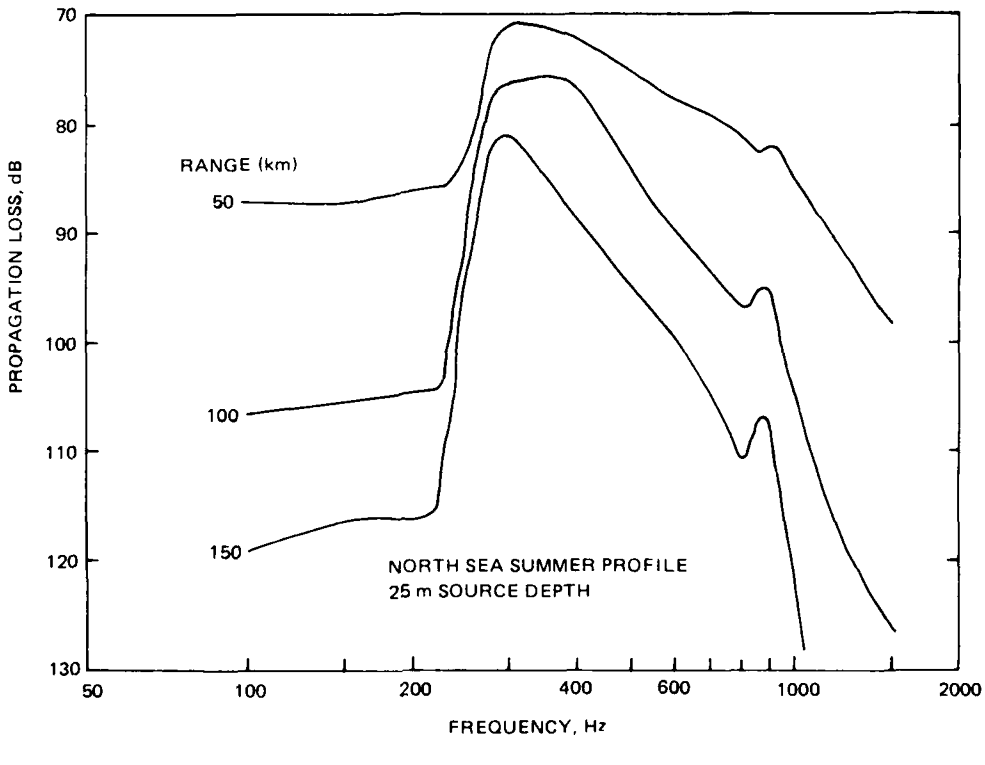

Figure 4.2. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. North Sea summer profile; source depth 25 m.

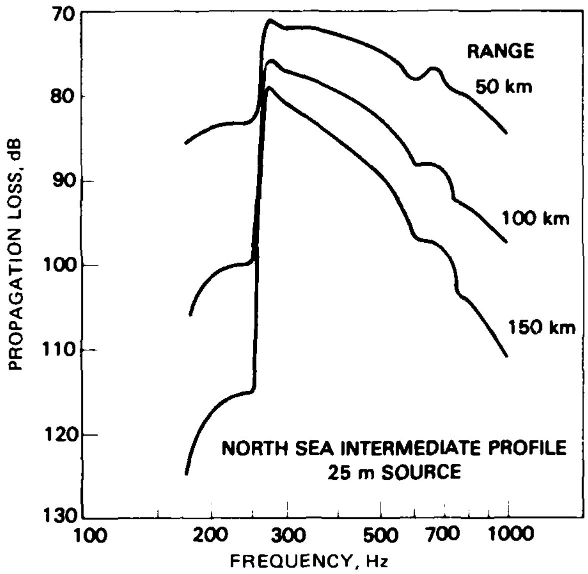

Figure 4.3. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. North Sea intermediate profile; source depth 25 m.

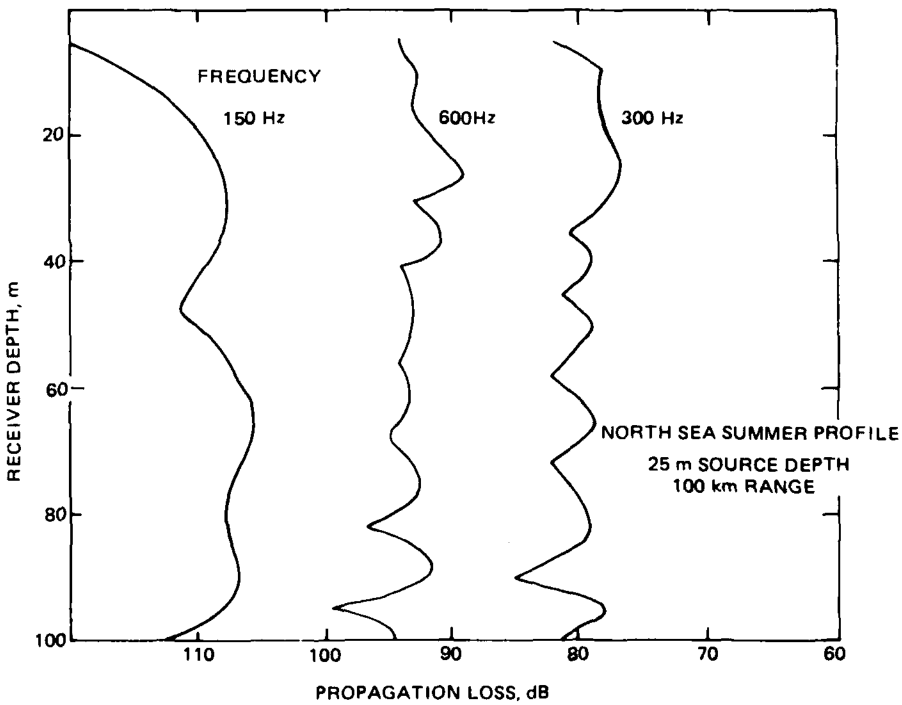

Figure 4.4. Propagation loss vs receiver depth for the freq' .ncies of 150, 300 and 600 Hz; North Sea summer profile; source depth 25 m.

and 600 Hz. The minimum loss is about 105 dB at 150 Hz, 89 dB at 600 Hz and 76 dB at 300 Hz. These are the values of propagation losses at 150, 300 and 600 Hz that were plotted in Figure 4.2 for the 100 km curve.

From Figure 4.4 we note that the minimum loss at 150 Hz occurs at a receiver depth of about 65 m, while at 300 Hz and 600 Hz the minimum loss is near the source depth at 25 m. In Figure 4.5 propagation loss versus receiver depth is given for the same three frequencies but for a source depth of 90 m. The minimum losses occur at receiver depths which are conditionally similar to those in Figure 4.5 (65 or 70 m at 150 Hz and near the source depth (90 m) at 300 and 600 Hz), but the propagation is much better for the 90 m source. Propagation losses for these frequencies are 5–20 dB less. The 90 m source is obviously more efficient in exciting those modes which propagate best by successive bottom bounces from this highly reflecting bottom at low frequencies.

Optimum frequencies of propagation for the North Sea site are about 300 Hz for both the winter and summer conditions. The optimum frequency of propagation is near 275 Hz for the intermediate profile. The low loss and sudden decrease in loss with frequency near 250–300 Hz (Figures 4.2 and 4.3) are due to a corresponding variation in the bottom reflection loss in the North Sea area. This is discussed in Section 4.2.

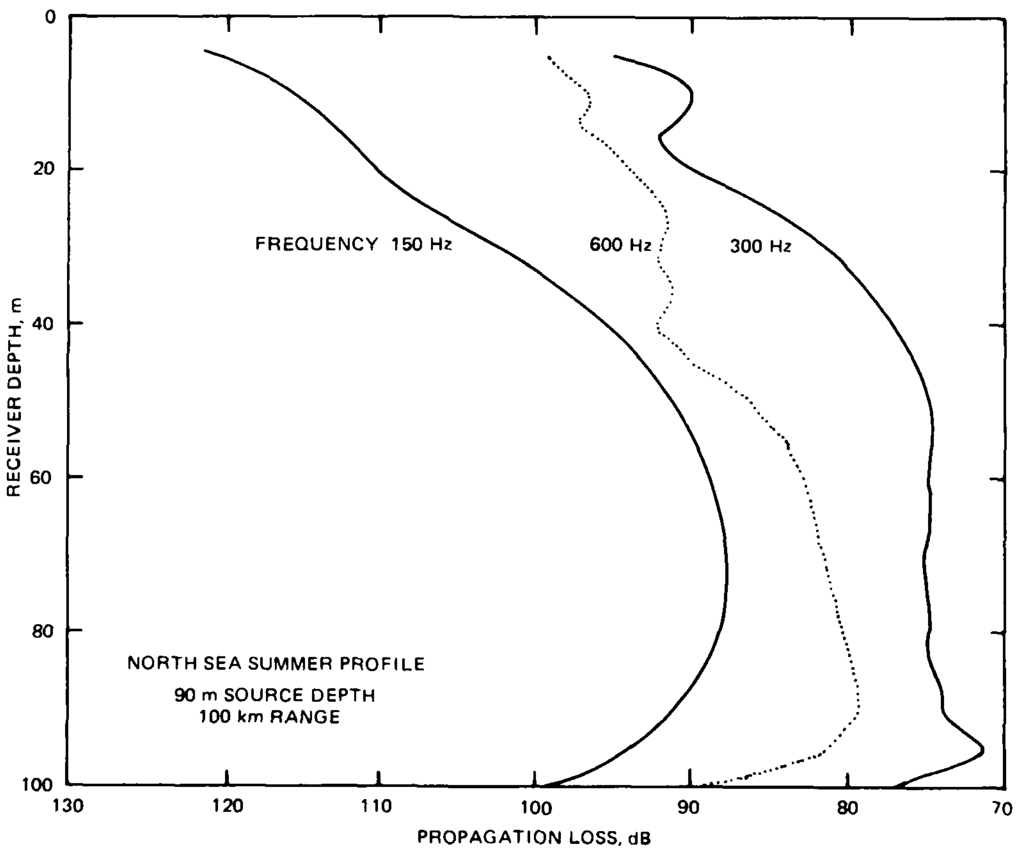

Figure 4.5. Propagation loss vs receiver depth for the frequencies of 150, 300 and 600 Hz; North Sea summer profile, source depth 90 m.

Except in the vicinity of the minimum loss the propagation losses for the summer and intermediate profiles are 10-30 dB greater than for the winter profile in the frequency range displayed. At optimum frequencies the propagation losses are about the same for the three profiles. The results for the summer profile (Figure 4.2) and the intermediate profile (Figure 4.3) differ mainly only at the frequency extremes, below 200 Hz and at about 700 Hz and longer ranges. The decrease in loss near 250-300 Hz is more abrupt for the intermediate profile and the decrease in loss near 700 Hz (Figure 4.3) is shifted to 900 Hz in Figure 4.2 for the summer profile. The most significant difference between these two profiles is that the sound speed at the source depth of 25 m is greater by about 6 m/s for the intermediate profile (see Figure 3.2).

4.1.2 Strait of Juan de Fuca

The water column and the sea floor sediments in the area of the Strait of Juan de Fuca site were modeled for propagation loss computations as shown in Tables 4.3 and 4.4.

Winter		Fall		Summer	
Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s
0	1480.3	0	1489.4	0	1497.5
25	1482.2	30	1491.1	10	1494.5
75	1483.8	50	1482.3	20	1482.5
130	1484.5	100	1479.6	30	1480.3
		130	1479.8	75	1477.7
				130	1477.9

Table 4.3. Sound speed in the water column.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom, m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)/Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
1	0.0	1529.0	1590.0	1.22	0.15	0.16	1.61
2	47.0	3000.0		-0.1	0.1		2.3

Table 4.4. Sediment parameters used in computations, Strait of Juan de Fuca.

Sediment sound speeds are given for the winter profiles. The adjustment is made for the other seasonal profiles to keep the ratio of sound speeds (surface sediment to bottom water) equal to 1.03. Density in the water is assumed to be 1.03 and a constant value in each sediment layer.

Propagation loss for optimum receiver depth as a function of frequency is shown in Figure 4.6 (winter), Figure 4.7 (summer) and Figure 4.8 (fall) for the different seasonal profiles. Optimum frequencies of propagation are about 300 Hz for the positive gradient, winter conditions, about 125 Hz for the non-positive summer profile and 900-1000 Hz for the fall profile. The propagation losses are much less for the winter profile, about 10 dB at optimum frequency and 10-50 dB less elsewhere. Propagation is slightly better at optimum frequency for fall compared to summer but is lower at other frequencies.

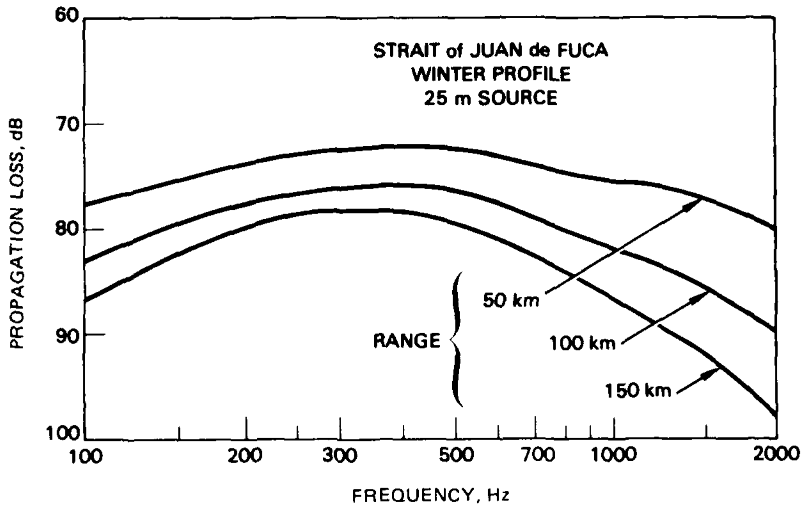

Figure 4.6. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Strait of San Juan de Fuca winter (positive gradient) profile; source depth 25 m.

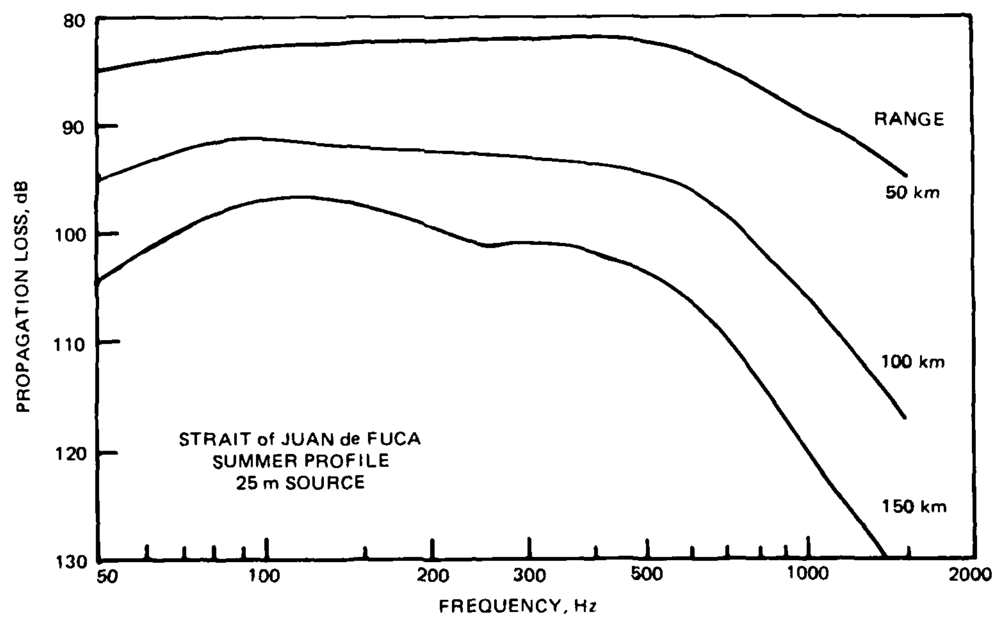

Figure 4.7. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Strait of Juan de Fuca summer (non positive) profile; source depth 25 m.

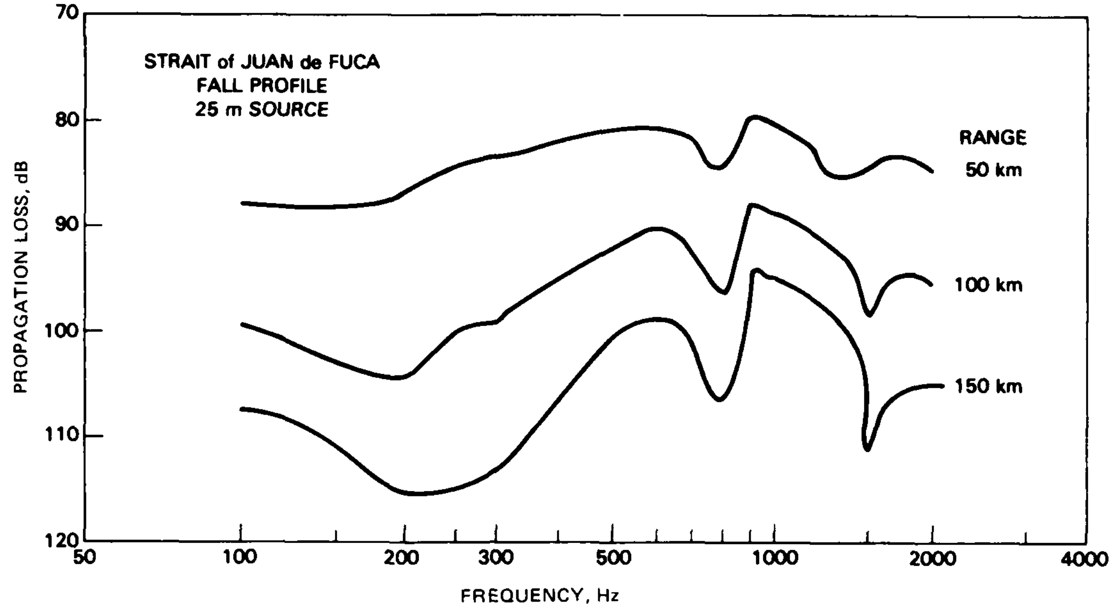

Figure 4.8. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100, and 150 km. Strait of Juan de Fuca fall profile; source depth 25 m.

The fall profile has a positive gradient to 30 m (see Figure 3.4), which includes the source at 25 m. This contributes to the irregularities in the propagation loss curves (Figure 4.8) near 900 Hz.

4.1.3 East of Singapore

The sound speed profiles and sea floor sediment parameters for the East of Singapore site are modeled for propagation loss computations in Tables 4.5 and 4.6.

Winter		Summer*	
Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s
0	1536.9	0	1542.3
10	1537.4	10	1542.0
50	1538.7	20	1541.9
		30	1541.35
		50	1541.45

*A non-positive gradient profile was chosen here because the author wanted to have contrasting winter and summer conditions.

Table 4.5. Sound speed in the water column, East of Singapore site.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom, m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)/Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
1	0.0	1523.79	1617.79	1.10	0.06	0.07	1.5
2	78.0	1830.0	1943.0	0.91	0.07	0.08	1.95
3	191.0	4200.0		-0.1	0.03		2.37

Table 4.6. Sediment parameters used in computations, East of Singapore.

The sediment sound speeds are given for the winter profile and should be adjusted for the summer case to keep the ratio of sound speeds (surface sediment/bottom water) to 0.99. The density of water was taken to be 1.02 and the density in each sediment layer was assumed to be constant.

Propagation loss for optimum receiver depth as a function of frequency is shown in Figure 4.9 (winter profile) and Figure 4.10 (summer profile). High bottom reflection losses exist at this site due to the slow sound speed in the sediment. Therefore, the propagation losses calculated for the summer profile are quite high and only visible on the graph at 50 km in the frequency range 800 to 4000 Hz and at 100 km for frequencies 2200-3200 Hz.

Optimum frequency of propagation is near 3000 Hz for the summer conditions and about 1000 Hz for winter conditions. The minimum loss is greater by more than 10 dB for the summer profile.

4.1.4 Lands End

Computational models for the water column (Table 4.7) and for the sediments (Table 4.8) for the Lands End site are the following:

Winter

Depth, m	Sound Speed, m/s
0	1491.1
10	1491.49
20	1491.51
125	1493.5

Summer*

Depth, m	Sound Speed, m/s
0	1515.6
10	1515.1
20	1515.0
30	1504.6
50	1494.3
75	1493.0
125	1493.8

Table 4.7. Sound speed in the water column, Lands End site.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
1	0.0	1670.0	1710.0	7.3	0.50	0.38	1.85
2	5.0	1710.0	1757.0	1.81	0.38	0.28	1.85
3	30.0	1800.0	2090.0	0.80	0.03	0.02	2.0
4	320.0	4360.0		-0.01	0.01		2.64

Table 4.8. Sediment parameters used in computations, Lands End.

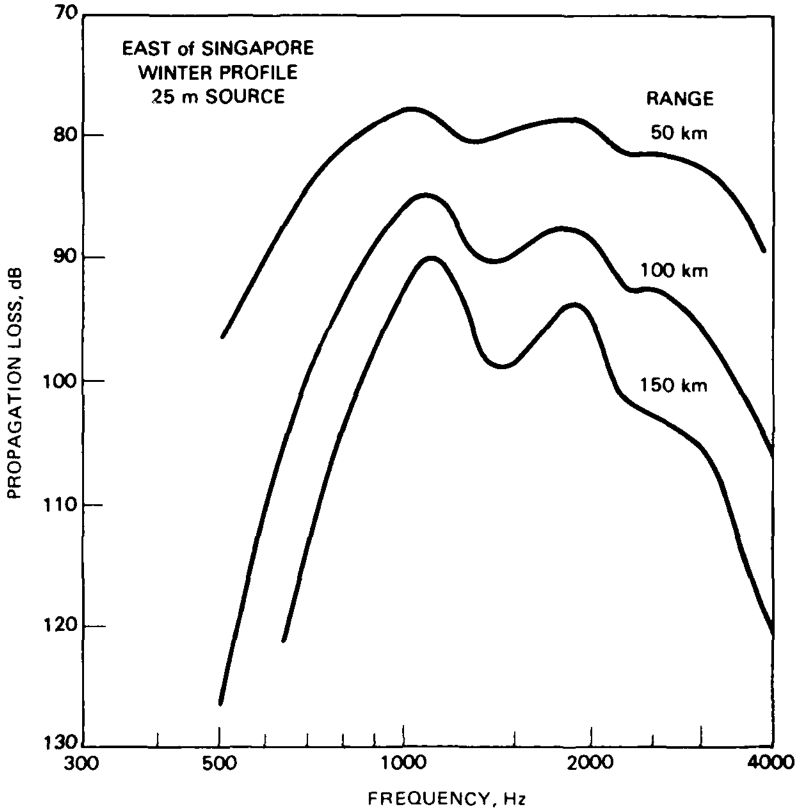

Figure 4.9. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. East of Singapore winter (positive gradient) profile; source depth 25 m.

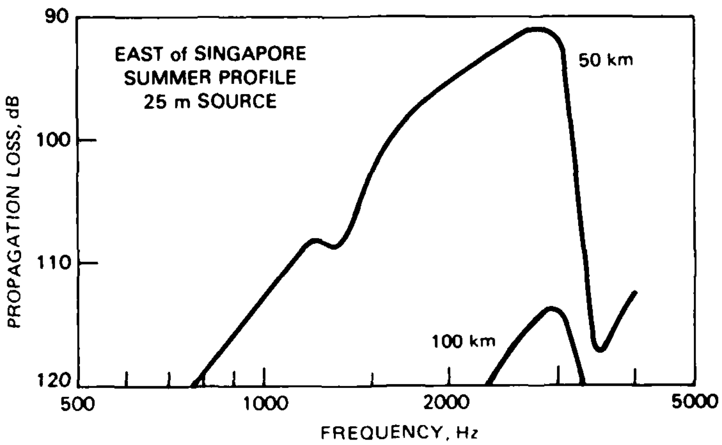

Figure 4.10. Propagation loss for optimum receiver depth vs frequency for ranges of 50 and 100 km. East of Singapore summer profile; source depth 25 m.

As in all of the computational models in this report, the listed sediment sound speeds are for the winter profile with the ratio of sound speeds (surface sediment/bottom water) equal to 1.12 for Lands End and adjusted accordingly for the summer profile.

Calculated minimum propagation losses as a function of frequency are shown in Figure 4.11 (winter profile) and Figure 4.12 (summer). The positive gradient conditions (winter, Figure 4.11) do not show much frequency dependence over the range shown. However, optimum frequencies of propagation are about 300 Hz for the winter profile (based on the propagation to 150 km) and about 900 Hz for the summer conditions. Also propagation losses are 10 dB greater for the summer profiles. The irregularities in the curves in Figure 4.12 (summer profile) are due to a near-isovelocity portion of the profile above 20 m (see discussion in Section 4.2.1).

4.1.5 Korea Strait

The computational models for the Korea Strait site are given in Table 4.9 for the water column and in Table 4.10 for the sediments.

Winter		Summer	
Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s
0	1503.0	0	1536.3
128	1505.24	20	1534.3
		30	1527.5
		50	1517.7
		128	1507.5

Table 4.9. Sound speed in the water column, Korea Strait.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom, m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)/Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
1	0.0	1759.0	1787.0	9.12	0.5	0.4	1.93
2	3.0	1600.0	2327.0	0.42	0.1	0.07	1.53
3	1003.0	4100.0		-0.1	0.03		2.33

Table 4.10. Sediment parameters used in computations, Korea Strait.

The sediment sound speeds are given for the winter model and should be adjusted to keep the ratio of sound speeds (surface sediment/bottom water) equal to 1.17 before calculations for the summer (or another) profile are performed. The density in the water column was 1.03 and the densities in each sediment layer are assumed constant within layers.

The sound speed at the top of the second layer of sediment in Table 4.10 is not the same as in Table 3.10. Difficulties in the normal mode calculations were experienced with the lower velocity. This sediment model is similar to the North Sea sediments in that each has a surface layer of fine sand of about the same sound speed and layer thickness (2 m for North Sea versus 3 m here) and no difficulties were experienced for the North

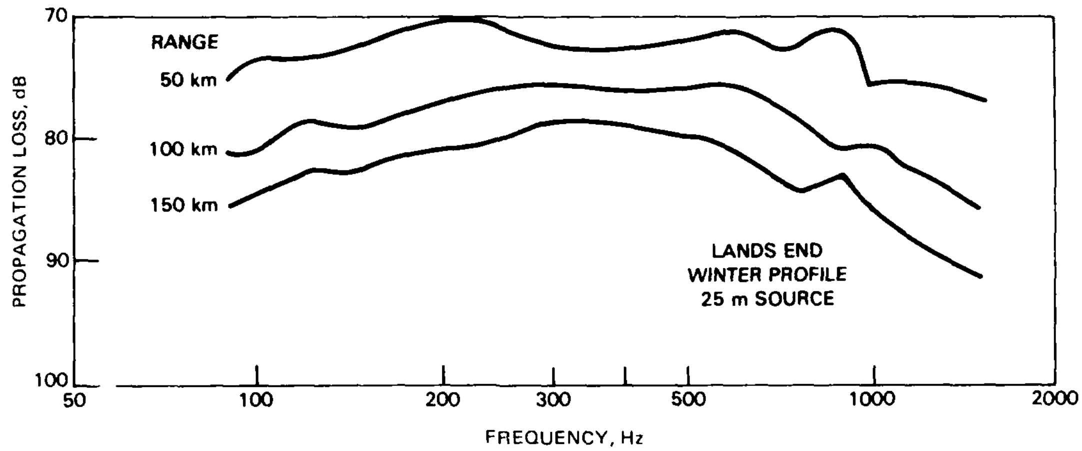

Figure 4.11. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Lands End winter (positive gradient) profile; source depth 25 m.

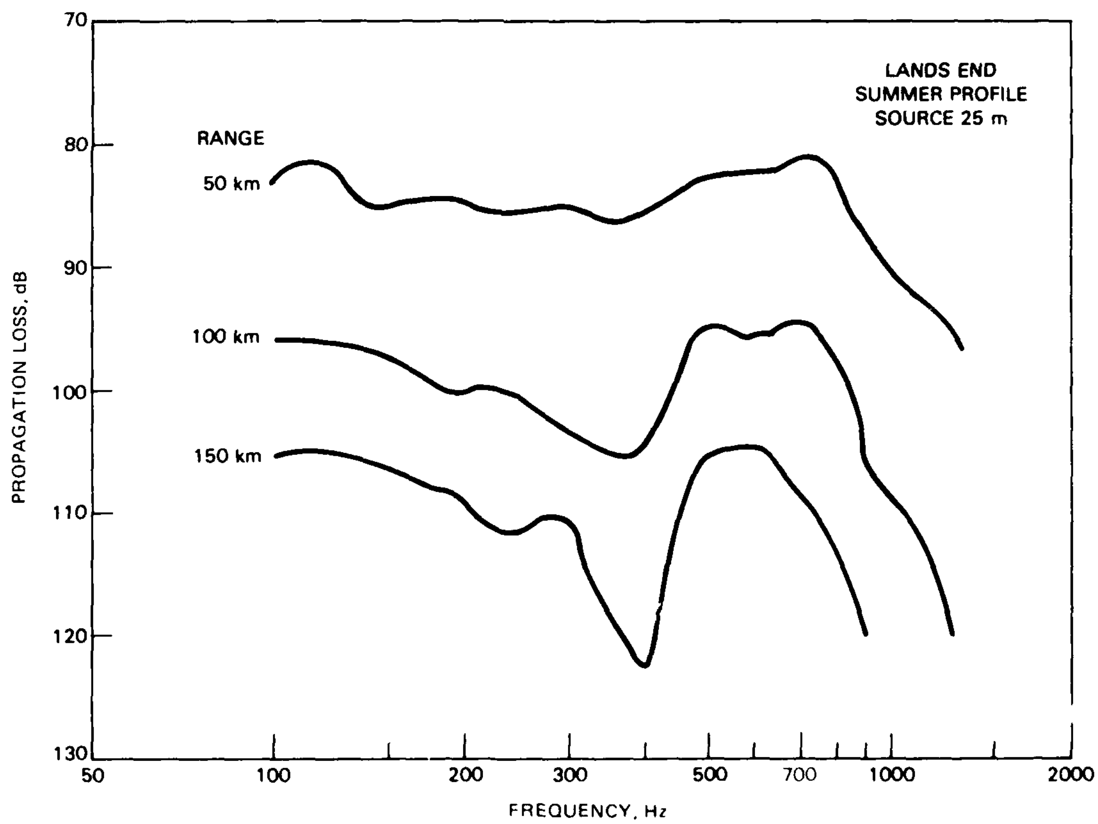

Figure 4.12. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Lands End summer profile; source depth 25 m.

Sea computations. Thus, in an attempt to overcome our present problems, the sound speed at the top of the second layer was increased to approach that in the North Sea model. A sound speed of 1600 m/s allowed convergence for modes of propagation with a consistent set of phase velocities.

Computed propagation losses are shown in Figure 4.13 for the winter profile. As evidenced by the anomalously high losses, we still have problems with the computational model. The failure to compute reasonable losses at frequencies of 250-500 Hz for the winter profile make this figure suspect. Since this sediment model (see Section 3.5) was of interim status, further investigation of this type of computational profile will be made at a future date. However, the optimum frequency of propagation for the positive gradient, winter case (Figure 4.13) is probably between 200 and 650 Hz.

Figures 4.14 and 4.15 show propagation losses calculated for the winter and summer profile conditions, respectively, and for a sea floor sediment model *without the 3-m sand layer*. Optimum frequencies of propagation are about 475 Hz for winter conditions and at low frequencies (less than 50 Hz) for the *summer* profile conditions. High bottom reflection losses and downward refraction combine to give *very* high losses for summer (Figure 4.15). A 100 m source depth was used to obtain losses at ranges of 25 and 50 km. Propagation losses at 50 km are about 40 dB higher at optimum frequencies for the summer profile versus the winter profile (114 dB at 40 Hz (Figure 4.15) versus 74 dB at 475 Hz (Figure 4.14)). *At 100 Hz the propagation loss is greater by over 60 dB at 50 km for the summer profile.*

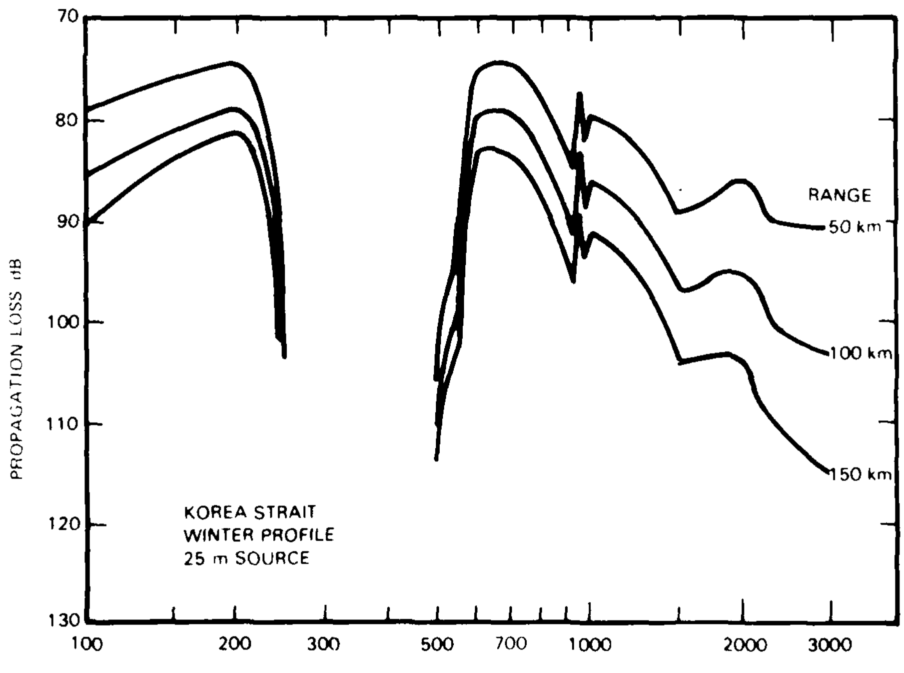

Figure 4.13. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Korea Strait winter profile, source depth 25 m.

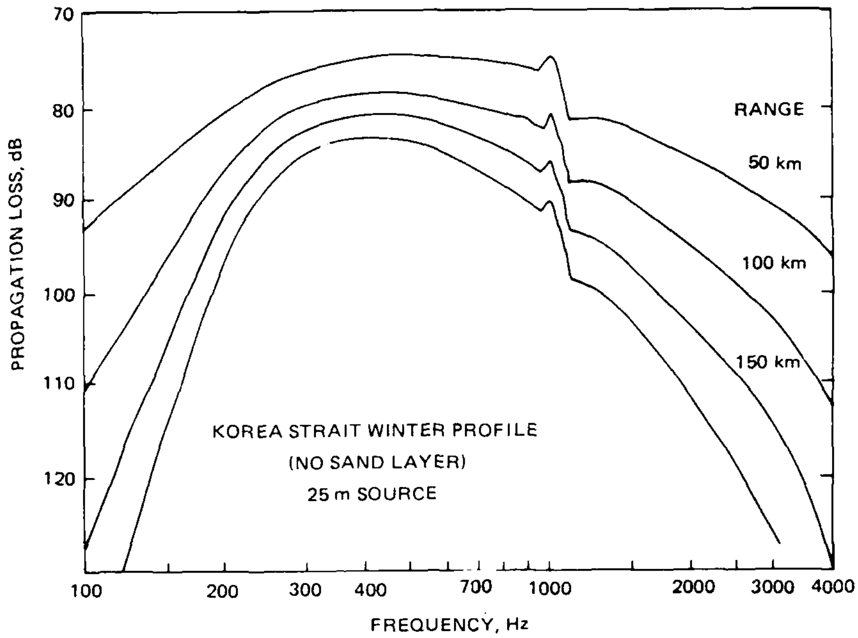

Figure 4.14. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Korea Strait winter profile without the top sediment sand layer; source depth 25 m.

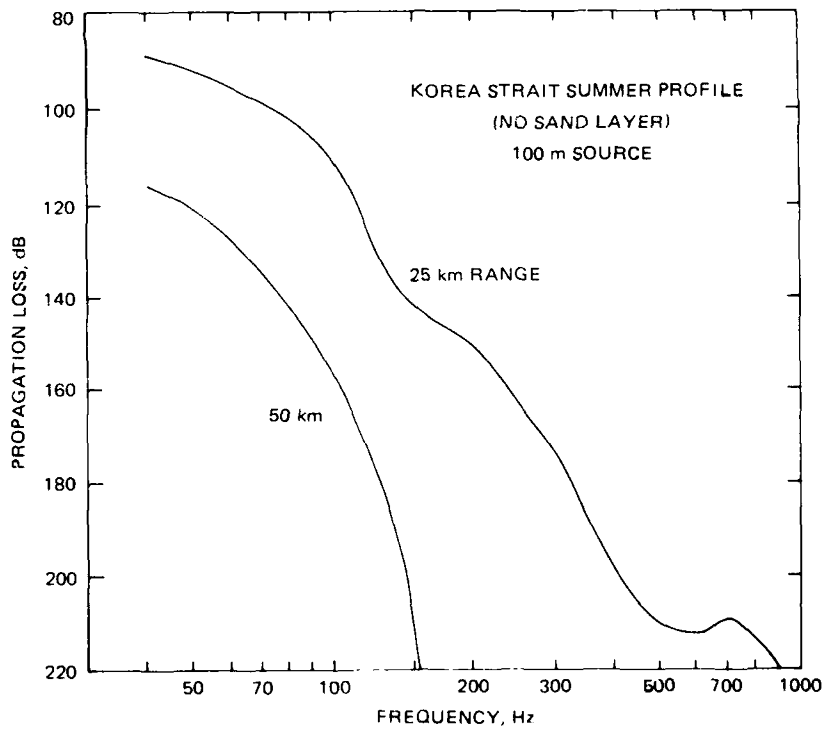

Figure 4.15. Propagation loss for optimum receiver depth vs frequency for ranges of 25 and 50 km. Korea Strait summer profile without the top sediment sand layer; source depth 100 m.

The principal reason for making the Figure 4.14 and 4.15 calculations is that the fine sand surface layer found at this site is not present in the sediments to the east (150–200 km from the center of the site) but is still well within the Strait (References 10, 11). Therefore, acoustic propagation can vary greatly within the Korea Strait due to position and frequencies of transmission even without a narrow frequency range.

A second sample of sound speed profiles taken 34.5°–35.5°N, 130°–131°E, (East Korea Strait) showed summer and winter profiles very similar to our sample and would have like characteristic profiles. However, profiles from that part of the Strait (not sampled) north of Tsushima Island may show different sound speed profiles due to the influx of cold water from the Sea of Japan as well as possibly different sediment properties. Acoustic propagation and optimum frequencies may differ in that part of the Strait as well.

4.1.6 Straits of Sicily

The numerical parameters for the models used in the calculations of propagation loss for the site in the Straits of Sicily are given in Table 4.11 (water column) and Table 4.12 (sediments for the shallow and deeper water models). As mentioned previously (Section 3.6) we have taken the two geoacoustic models from Reference 13, that are applicable to sediments in water that is shoal of 200 m and to water depths greater than 500 m, respectively. The sound speed profiles representative of this site are given in Table 3.11. The deeper profiles (to 500 m) are extensions of the sound speed profiles to 150–200 depths.

	Winter		Summer	
	Depth, m	Sound Speed, m/s	Depth, m	Sound Speed, m/s
	0	1509.3	0	1535.0
	50	1509.7	10	1535.5
	100	1509.5	20	1526.5
Depth of shallow model →	165	1512.1	60	1515.5
	500	1517.0	125	1511.7
			150	1511.8
			165	1512.5
Water depth of deeper model →			500	1516.8

Table 4.11. Sound speed in the water column, Straits of Sicily.

Bottom Layer Number	Sediment Depth, m	Sound Speed Top, m/s	Sound Speed Bottom, m/s	Gradient Top, s^{-1}	Absorption Top, (dB/km)/Hz	Absorption Bottom, (dB/km)/Hz	Density, g/cm^3
165 m Model: Surface sediment/bottom water = 1.11							
1	0.0	1678.0	1695.5	8.62	0.50	0.45	1.81
2	2.0	1695.5	1751.0	3.53	0.45	0.31	1.81
3	17.0	2200.0		0.1	0.02		2.16
500 m Model: Surface sediment bottom water = 0.99							
1	0.0	1501.3	1777.3	0.86	0.027	.0345	1.52
2	250.0	1777.3	1936.3	0.56	0.0345	.0235	1.83
3	500.0	2200.0		-0.1	0.02		2.16

Table 4.12. Sediment parameters used in computations, Straits of Sicily.

Calculated minimum propagation losses as a function of frequency are shown in Figure 4.16 (winter profile) and Figure 4.17 (summer profile) for the 165 m water depth. The propagation losses in the positive gradient case (Figure 4.16) are much less (10–15 dB at 100 Hz) than those in the downward refraction case (Figure 4.17), especially at the ranges of 100 and 150 km. However, at the 50 km range and optimum frequencies of propagation, 250 Hz for the winter profile and 650 Hz for the summer profile (downward refraction), the difference is only 5 dB.

Figure 4.18 (winter profile) and Figure 4.19 (summer profile) show the minimum propagation loss calculated for ranges of 50, 100 and 150 km for water depth of 500 m. Optimum frequency of propagation for the winter profile is about 300 Hz, nearly equal to that for the 165 m depth. For the downward refraction case (summer profile) the optimum frequency of propagation is about 40 Hz. The propagation losses for the summer profile are much greater than those for the winter profile. At 100 Hz and the range of 100 km, the difference is 20 dB. At 200 Hz and 50 km, the propagation loss is 15 dB greater in the downward refraction case.

Except at low frequencies (less than 100 Hz), the propagation losses for the 165 m water depths (shallow) are less than the losses for the 500 m depth. For the winter profiles (Figure 4.16 and Figure 4.18) the propagation losses are 10–20 dB less for the shallow case at frequencies above 500 Hz. Comparisons between Figures 4.17 and 4.19 (summer profiles) show even greater differences. Propagation losses are 10–60 dB less at 50 km for the 165 m depth. At frequencies below 100 Hz, the propagation loss curves for the 165 m depth and for 100 and 150 km ranges show greater loss with decreasing frequency so at 50–70 Hz the propagation losses are nearly equal at the 100 km range and are less at the 150 km range for the 500 m water depth. In these cases the optimum receiver depth was near the bottom.

4.2 Propagation Loss Comparisons

For purpose of discussion and illustration, comparisons between the first four sites will be discussed as a group. Also, a natural division arises due to the questionable results for the Korea Strait and to the two water depths and two sediment models in the Straits of Sicily.

4.2.1 Comparison Among Four Areas

Figure 4.20 compares the propagation losses calculated for the winter (positive gradient) sound speed profiles for four areas, the North Sea, Lands End, Strait of Juan de Fuca and East of Singapore sites, at the range of 50 km. Figure 4.21 is a similar comparison for the summer profiles. With the exceptions noted below, the propagation losses for the winter profiles generally are about 10 dB less than for the summer profiles. The East of Singapore site is very different from the others as the result of a much greater bottom loss. The sediment here is a fine grained clay with a sound speed less than that of the bottom water, which is very different from the silt and sand sediments of the other three areas.

Figure 4.22 shows bottom reflection losses for each area at two frequencies, 200 and 1000 Hz. These losses were determined by the normal mode program at the grazing angles corresponding to the modes. Smooth curves have been drawn through those points and arbitrarily brought to zero loss at zero grazing angle. The much greater bottom losses for the East of Singapore site are readily seen in this figure.

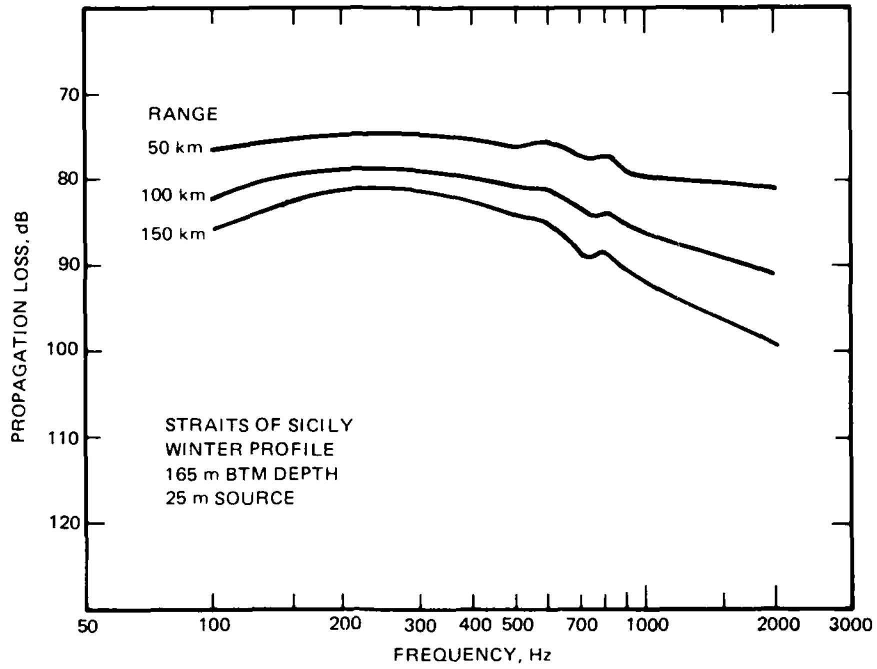

Figure 4.16. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Straits of Sicily winter profile, 165 m bottom depth; source depth 25 m.

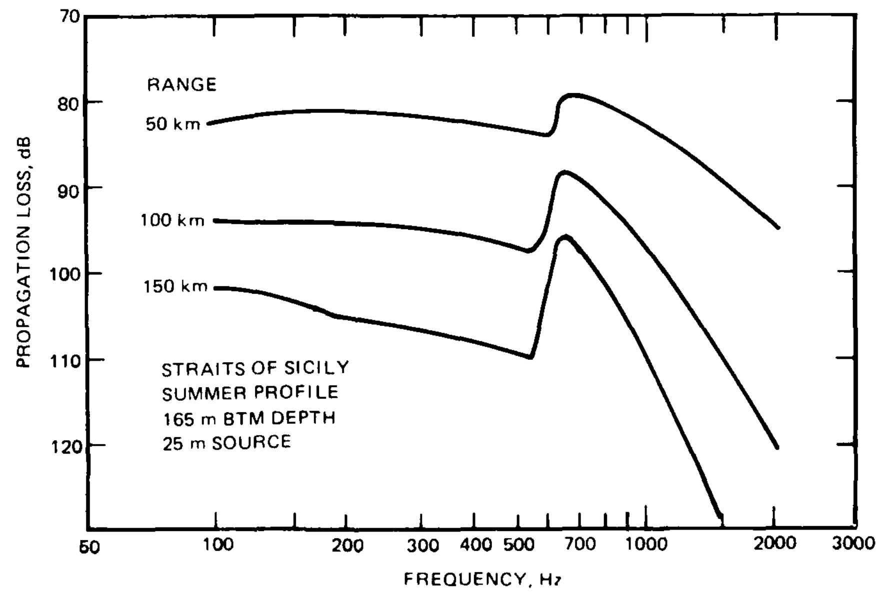

Figure 4.17. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Straits of Sicily summer profile, 165 m bottom depth; source depth 25 m.

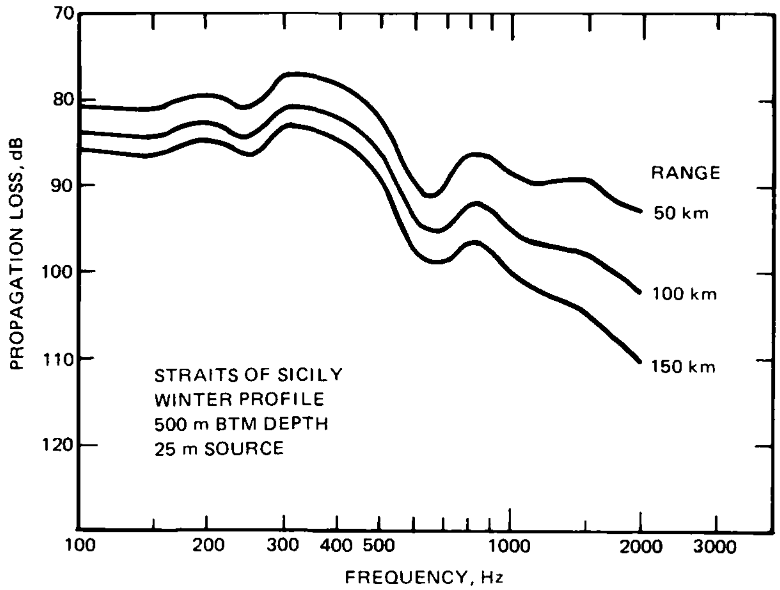

Figure 4.18. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Straits of Sicily winter profile, 500 m bottom depth; source depth 25 m.

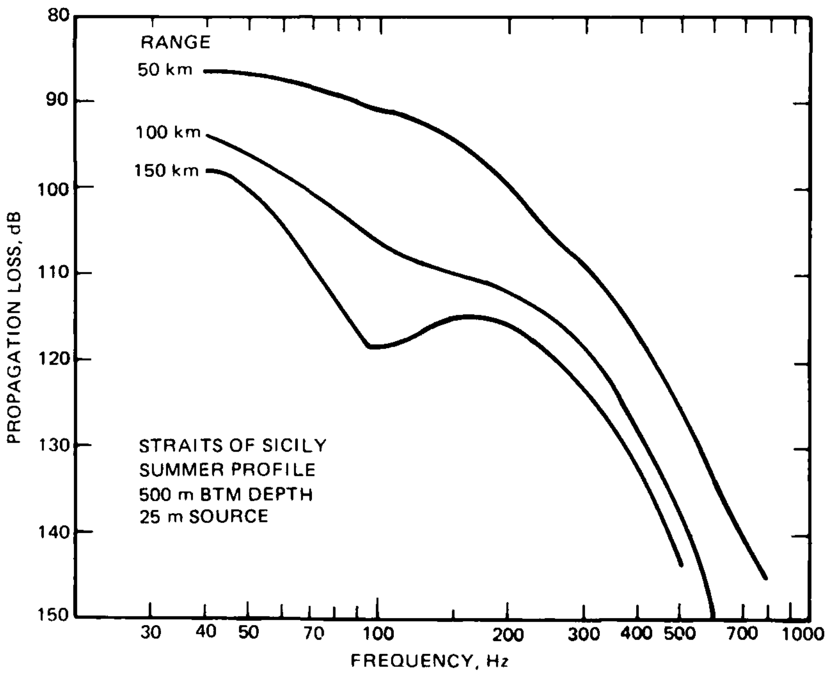

Figure 4.19. Propagation loss for optimum receiver depth vs frequency for ranges of 50, 100 and 150 km. Straits of Sicily summer profile (downward refracting), 500 m bottom depth; source depth 25 m.

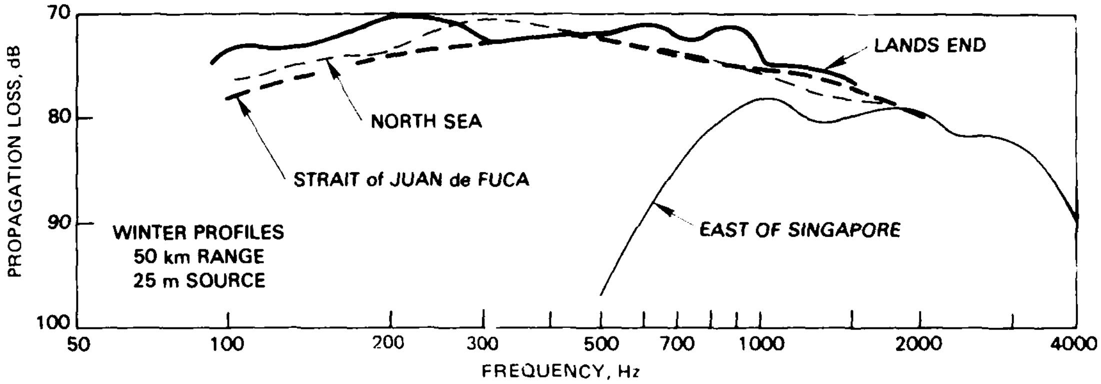

Figure 4.20. Comparison of propagation loss for optimum receiver depth vs frequency results for four sites and the 50 km range; source depth 25 m (winter profiles).

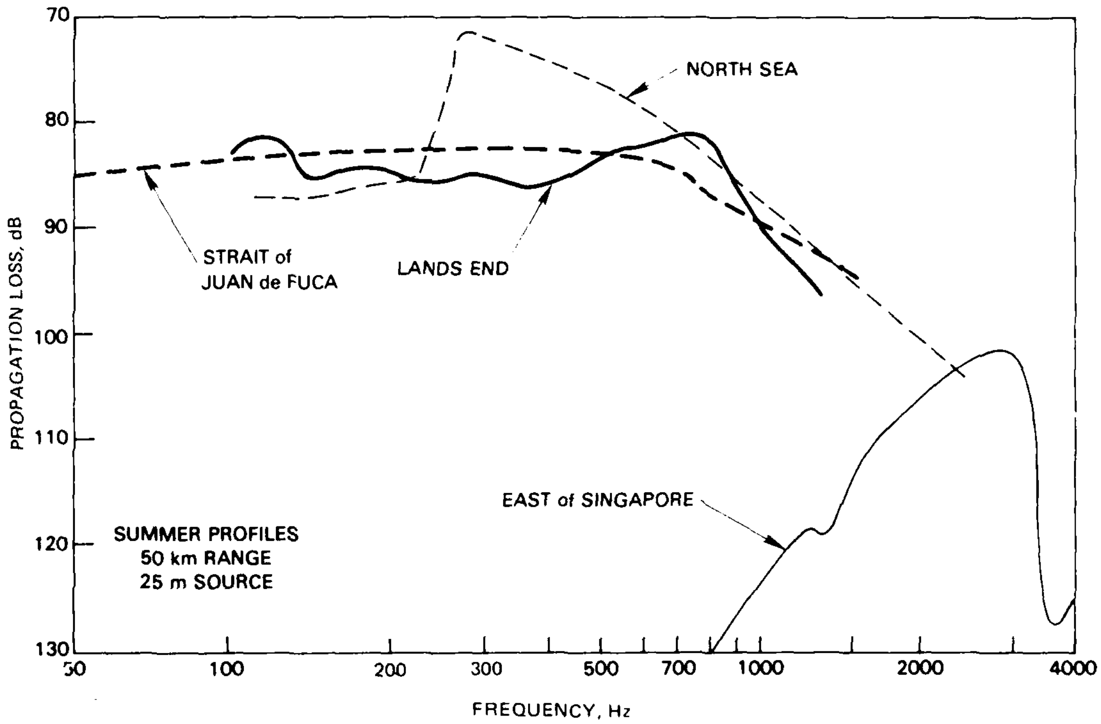

Figure 4.21. Comparison of propagation loss for optimum receiver depth vs frequency results for four sites and the 50 km range; source depth 25 m (summer profiles).

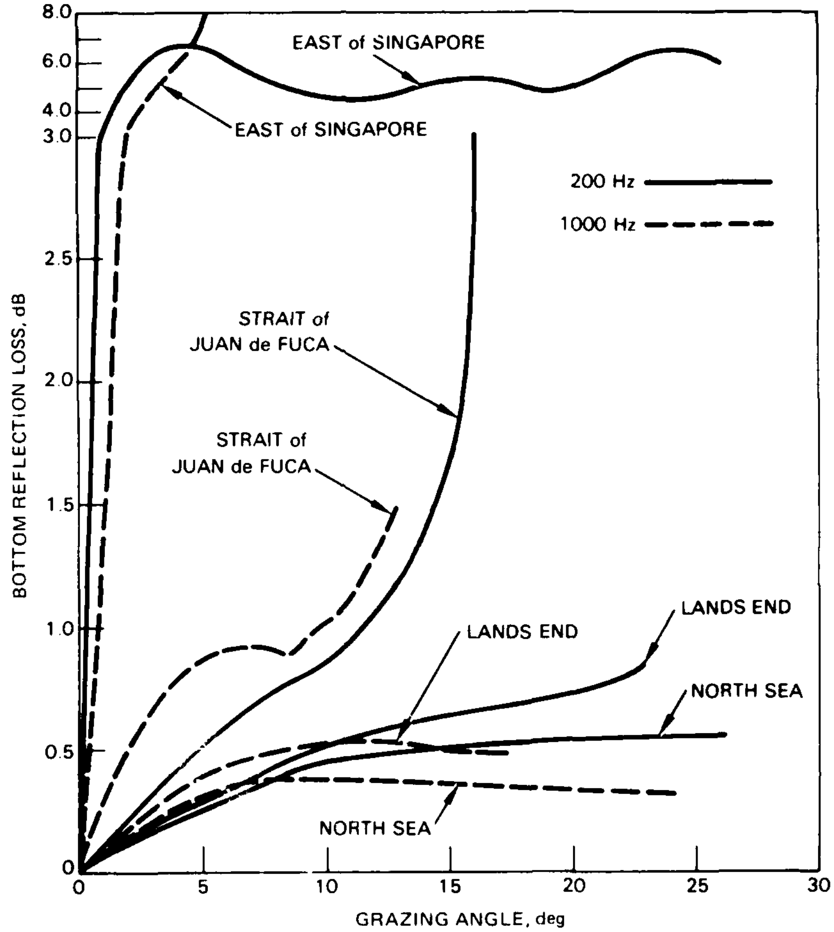

Figure 4.22. Bottom reflection loss vs grazing angle for the four sites at frequencies of 200 and 1000 Hz.

The East of Singapore summer profile has its best propagation at frequencies between 1500 and 3000 Hz (Figure 4.21). This propagation is due to a weak refractive duct in the sound speed profile (see Figure 3.6) with a sound axis depth of 30 m. The source at 25 m is just out of this duct and energy reaches it by diffraction. Thus, the propagation here is a sensitive function of source depth. (In these calculations, receiver depth is optimized, i.e., taken at the depth of maximum propagation, which in this case was near 30 m depth).

Of these four areas, East of Singapore best illustrates the phenomenon that led to the initiation of this investigation: when a surface duct exists in shallow water, it dominates the propagation and leads to a completely different frequency of maximum propagation. It is now apparent that high bottom loss is required to display this effect fully. In this area the high bottom loss and the small water depth (50 m) combined to produce a bottom reflected propagation loss that is entirely off the scale of Figure 4.21. A range less than 50 km would be required to show the nature of the bottom reflected propagation.

A feature in Figure 4.21 is the very low propagation loss for the North Sea summer profile near 250–600 Hz. This results from an unusual bottom reflection loss curve as shown in Figure 4.23. For grazing angles less than about 10 degrees, an interval of almost perfect reflection can be seen for the frequencies of 250 and 275 Hz. Several modes occupy this interval and propagate with negligible loss. The source depth will strongly determine how these modes will enter the propagation. The peak in Figure 4.21 is at 275 Hz. This discussion also helps to explain the sudden decrease in loss in Figures 4.2 and 4.3.

The bottom model for this site (North Sea) has a 2 m depth of sand as the first sediment layer. The sound speed in this sand layer is very high and the critical angle is about 33 degrees grazing. However, either its shallow depth (2 m) or large absorption causes the rapid increase in reflection loss near the 10 degrees grazing angle. At lower angles nearly perfect external reflection occurs. However, at high frequencies near 1 kHz, the loss becomes more in line with the other areas.

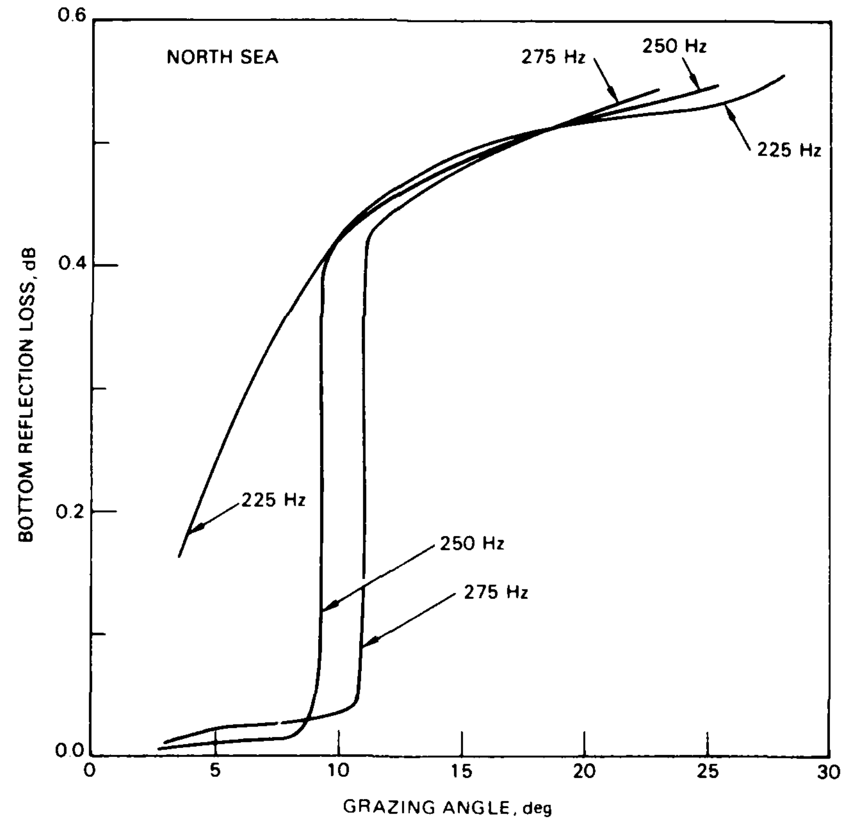

Figure 4.23. Bottom reflection loss vs grazing angle for the North Sea site and frequencies of 225, 250 and 275 Hz.

Another small anomaly in Figure 4.21 is the minimum in the propagation loss for the Lands End summer profile near 800 Hz. This irregularity arises from the sound speed profile which has near isovelocity water in the top 20 meters. Rays vertexing at this depth have extra long loop lengths and thus reflect from the bottom less often and suffer less bottom loss. When the mode structure provides a mode which corresponds to this effect, this mode has smaller loss. This happens near 800 Hz.

4.2.2 Propagation Loss Comparisons Including the Korea Strait and the Straits of Sicily

Figure 4.24 compares the propagation losses calculated for the winter profiles for the Korea Strait and the Straits of Sicily (two water depths) at the 50 km range with an average loss curve for the sand sediment areas of Figure 4.20. The region between 200 and 600 Hz on the Korea Strait curve is dotted in to indicate the probable losses there. A similar comparison for the summer profiles is shown in Figure 4.25 with the Korea Strait and Lands End omitted. The propagation losses for the 165 m Straits of Sicily, winter profile, are nearly the same as the average losses for the previously noted sand areas and are about 10 dB lower than those for the summer profiles except in the region of 600 to 650 Hz. The summer profile losses there show a shift in the loss curve in the amount of 4–5 dB less loss. This arises from the nature of the bottom reflection loss dependence upon frequency. At 600 Hz, the magnitude of the bottom loss increases suddenly at about 7.4 degrees, while at 650 Hz a similar increase is at about 9.9 degrees. This causes the anomaly in the propagation loss at that point. Beyond 700 Hz, the loss resumes an increase in line with other curves in that region. At this time we are not aware of the physical mechanism involved.

The most distinct feature of Figure 4.25 is the high loss shown for the 500 m depth, Straits of Sicily. The profile is downward refracting to a slow bottom. These conditions lead to high propagation losses. This case is discussed further in the next section (4.2.3).

4.2.3 Effects of Sediment Attenuation

The sediment models for the Straits of Sicily, as mentioned previously, were taken from Reference 13. In that report, Matthews gives two models (Geoacoustical Models IIA and IIB) for water depths in excess of 500 m which differ only in the attenuation coefficient. We have used the "high attenuation" model (IIB) in Table 4.13. The attenuation coefficients differ by a factor of 6 at the top of the first sediment layer. Table 4.13 compares the attenuation of the two models.

Depth, m	Attenuation K, in (dB/km)/Hz	
	Model IIA	Model IIB
0	.0045	.0270
250	.0170	.0345
500	.0160	.0235

Table 4.13. Attenuation coefficients.

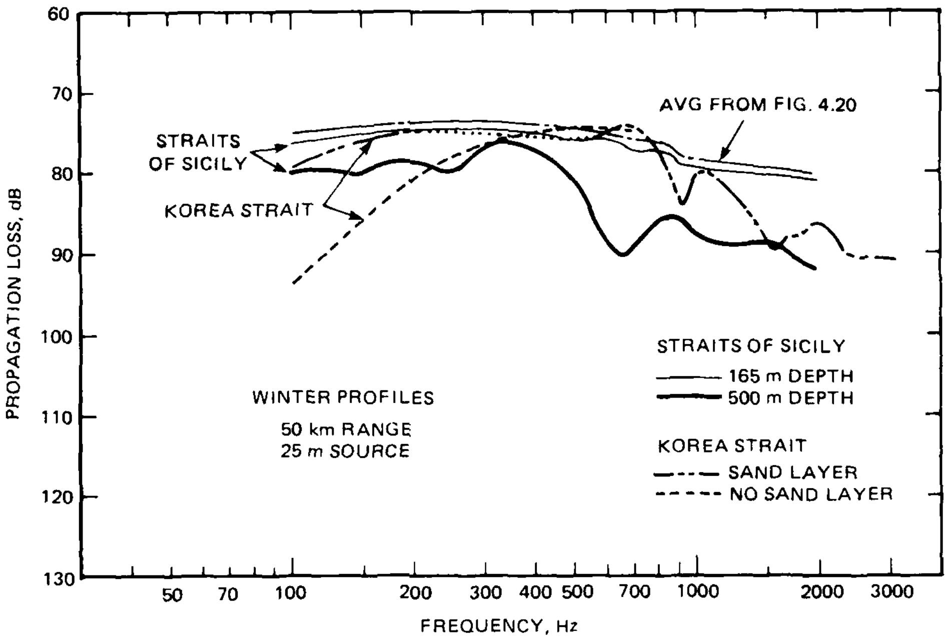

Figure 4.24. Comparison of propagation loss for optimum receiver depth vs frequency results for the 50 km range (winter profiles).

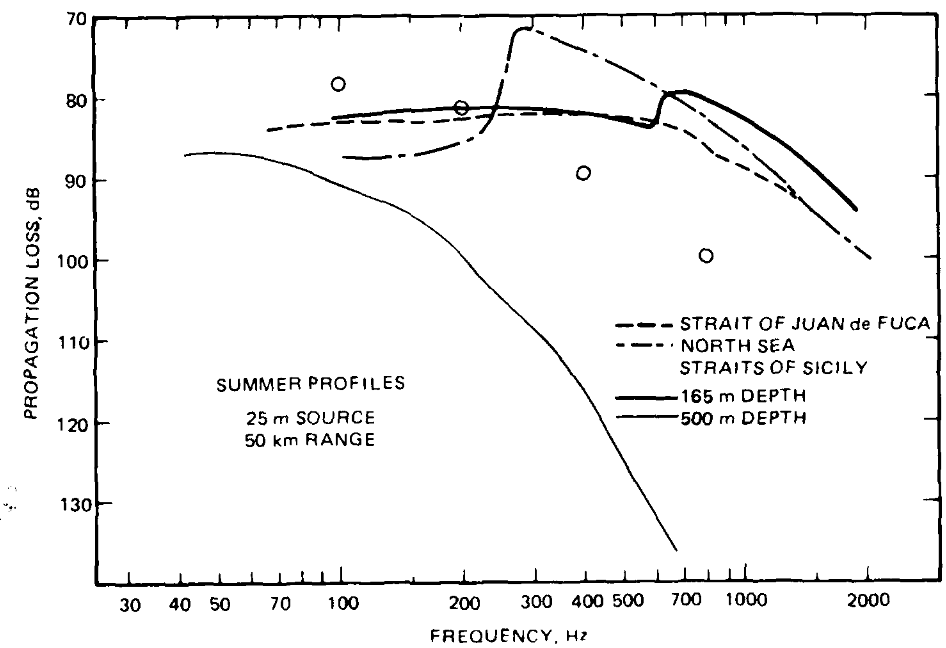

Figure 4.25. Comparison of propagation loss for optimum receiver depth vs frequency results for the 50 km range (summer profiles).

The propagation losses for the summer profile, 500 m depth, Straits of Sicily (see Figure 4.25) are quite high. Although the cause for this is not immediately evident, high bottom reflection losses are suspected. Thus, calculations of propagation loss and bottom reflection loss were made for several frequencies using both the low and high attenuation models. The resulting propagation losses (low attenuation) at 100, 200, 400 and 800 Hz are plotted in Figure 4.25. They are represented by the open circles. The differences between the computed losses are high, 12 dB at 100 Hz, 18 dB at 200 Hz, 26 dB at 400 Hz and over 40 dB at 800 Hz.

Figures 4.26 and 4.27 show bottom reflection loss versus grazing angle for the low and high attenuation models and for the frequencies of 100, 200, 400 and 800 Hz. There are fluctuations in the data which are indicative of the layering in the sediments. The fluctuations are greater in magnitude as the frequency is increased; the layers become a major bottom interaction mechanism.

The differences in bottom reflection loss calculated for the two sediment models are large even at 100 Hz: 1.5 dB at 10°, etc. These data are one output of the normal mode model and thus the largest angle shown is the grazing angle associated with the last mode used in the calculation.

4.3 Comparison With Cylindrical Spreading

The normal mode model used here assumes a perfectly reflecting sea surface, so the only sources of loss are bottom loss and volume attenuation. This can be used to classify different propagation loss curves. Figure 4.28 shows curves for cylindrical spreading loss plus volume attenuation which we computed by Thorp's equation (Reference 8) for the three ranges 50, 100 and 150 km. Actual propagation loss cannot fit these curves in absolute value since the propagation must fall off initially with spherical spreading loss. However, the shape should be the same if absorption is the only frequency dependent mechanism at work. The winter profile results of Figure 4.20 are found to fit the 50 m range quite well above 200 Hz. The loss for the summer profiles (Figures 4.21 and 4.25) increases more rapidly with frequency than does the absorption only curve (Figure 4.28). This is to be expected since bottom loss is a factor in the summer (downward refracting) profiles and bottom loss generally increases with frequency.

The increase in propagation loss at low frequencies over that of the absorption only curve occurs because at sufficiently low frequencies no modes are trapped by the positive gradients. Then all modes are equivalent to bottom reflected paths. With decreasing frequency, these paths become steeper resulting in both greater reflection loss and more reflections, since the distance between reflections are closer. This is most evident in the East of Singapore case and can be easily seen in the propagation loss curves for the Korea Strait (Figure 4.24).

The three curves of Figure 4.28 can be used also to indicate ducted propagation by noting the distance between them at a given frequency and comparing this distance with any propagation loss plots set for the same three ranges. If the distances are the same, then only absorption and cylindrical spreading are present. (The computational model used here has no surface reflection loss.) By such comparisons, we find that the propagation is ducted in a nearly lossless duct in the following:

- Winter Profile Cases

  North Sea above 400 Hz (Figure 4.1)
  Lands End above 300 Hz (Figure 4.11)

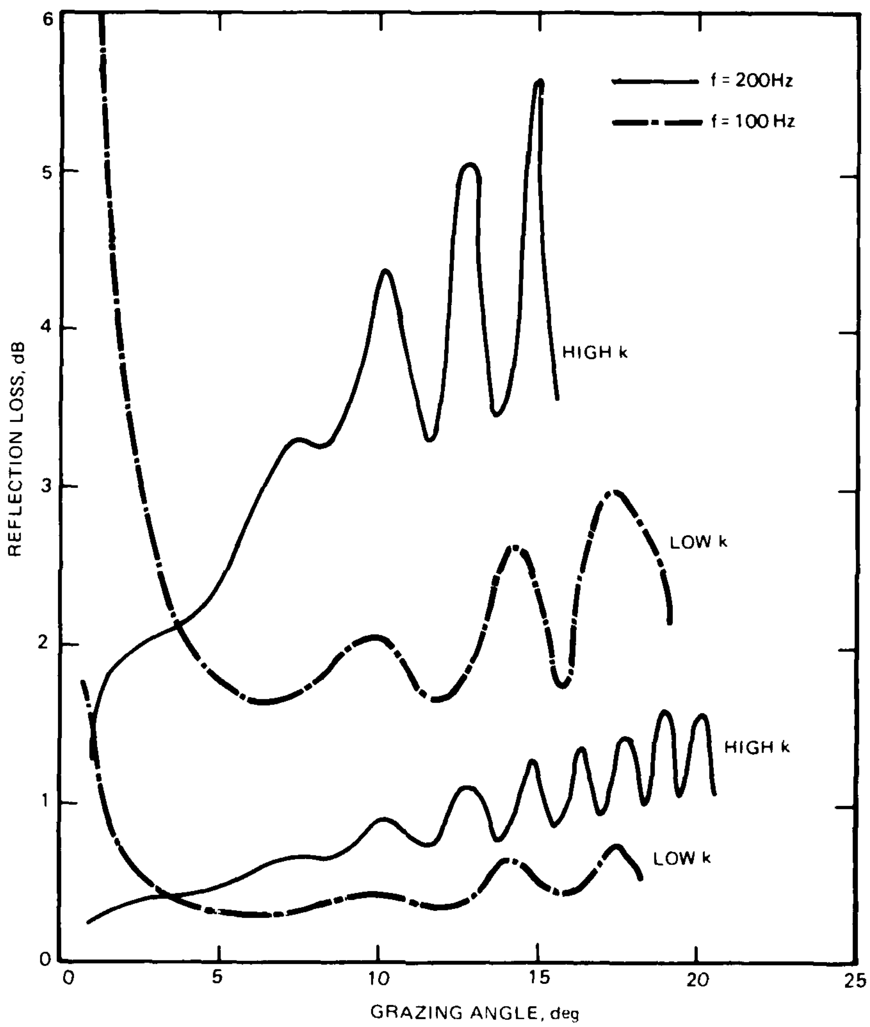

Figure 4.26. Bottom reflection loss vs grazing angle for the Straits of Sicily for the frequencies of 100 and 200 Hz and for the two sediment attenuations.

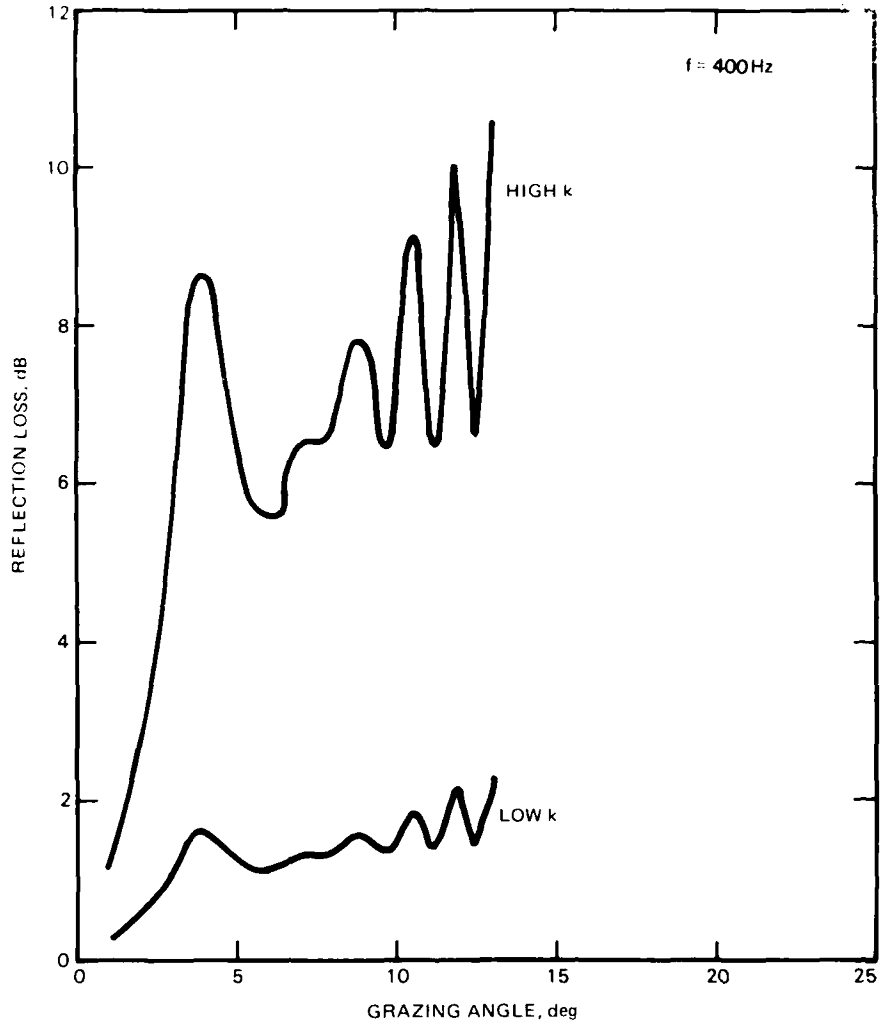

Figure 4.27a. Bottom reflection loss for the Straits of Sicily for two frequencies and two sediment attenuations. Frequency of 400 Hz.

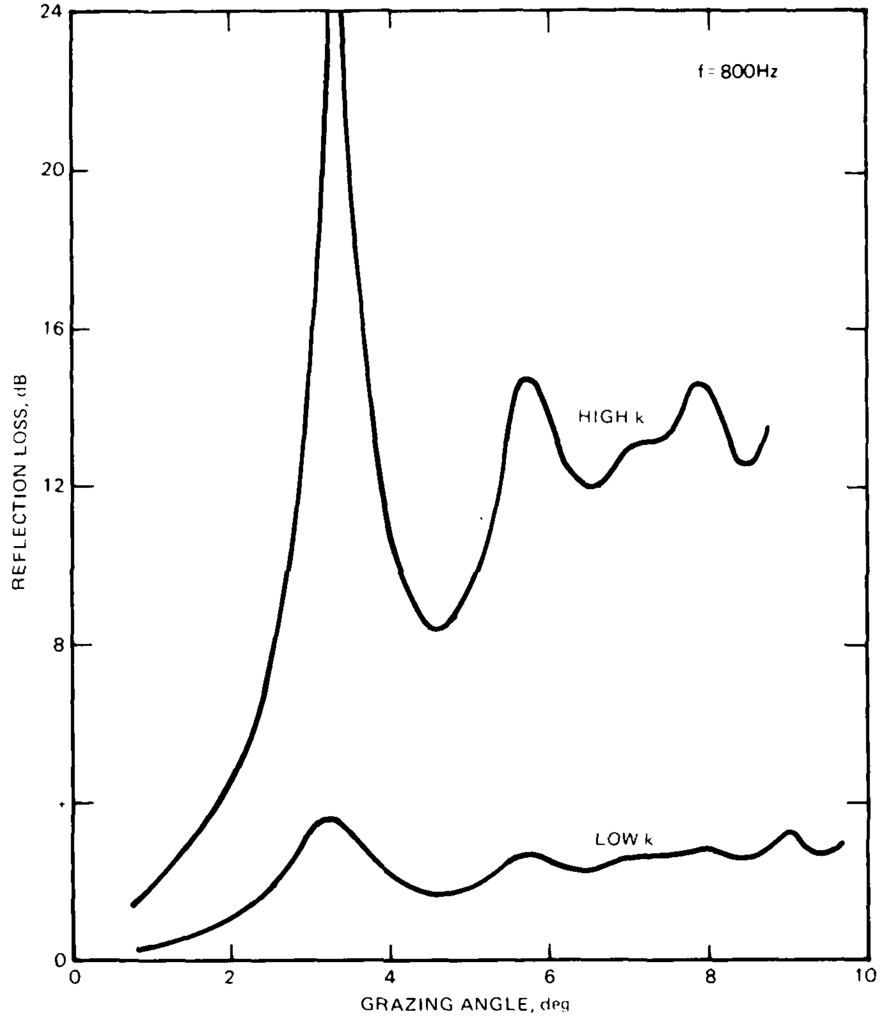

Figure 4.27b. Bottom reflection loss for the Straits of Sicily for two frequencies and two sediment attenuations. Frequency of 800 Hz.

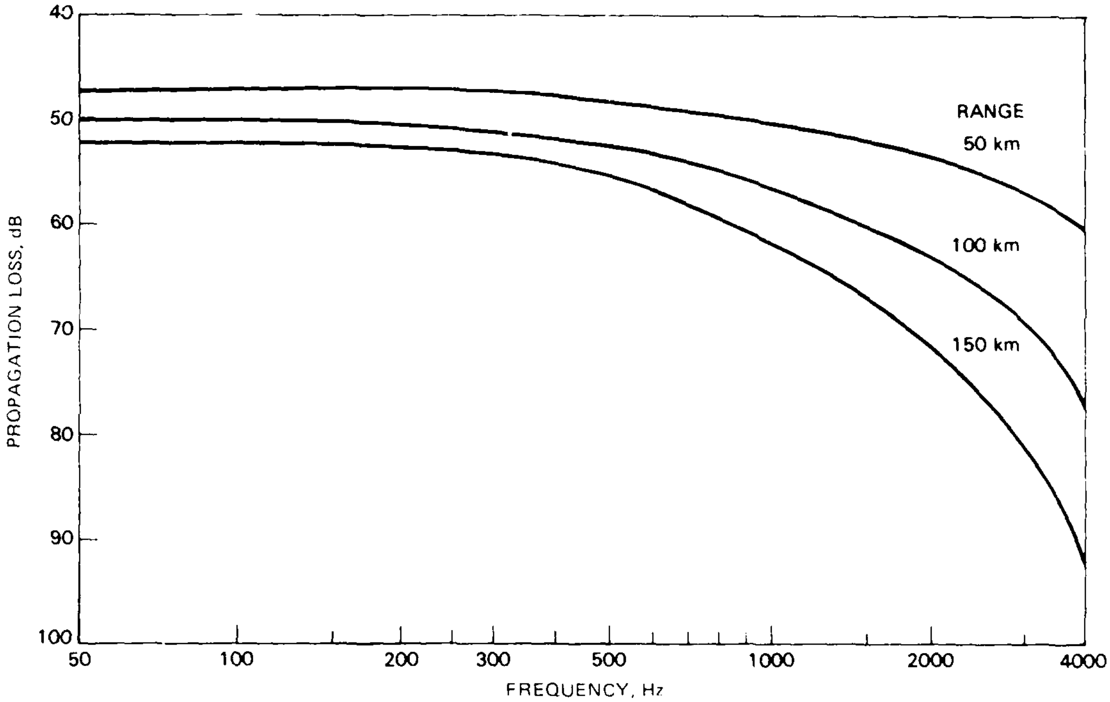

Figure 4.28. Cylindrical spreading loss plus absorption loss in the water as a function of frequency for fixed ranges of 50, 100 and 150 km.

Strait of Juan de Fuca above 300 Hz (Figure 4.6)
East of Singapore above 1000 Hz (Figure 4.9)

- Summer and Intermediate Profile Cases

  North Sea around 300 Hz (Figures 4.2, 4.3)

- Fall Profile Case

  Strait of Juan de Fuca above 900 Hz (Figure 4.8)

Examples in other areas are:

- Winter Profile Cases

  Korea Strait above 600 Hz (Figure 4.13, sand layer)
  Korea Strait above 400 Hz (Figure 4.15, no sand layer)
  Straits of Sicily above 100 Hz, 500 m depth (Figure 4.18)
  Straits of Sicily around 300–400 Hz, 165 m depth (Figure 4.16)

We find a surface duct or a nearby lossless bottom reflected duct in each of these cases.

5. SUMMARY OF RESULTS AND CONCLUSIONS

1. Nine shallow water areas were examined for the presence of positive sound speed gradients. Ninety percent of the fall-winter sound speed profiles and 31 percent of the spring-summer profiles were of the positive gradient type.

2. In three areas 60–76 percent of the spring-summer profiles were positive gradient. These were the low latitude areas, East of Singapore, the North Coast of Brazil and the Bass Strait, the region between Australia and Tasmania.

3. Positive gradient (winter) profiles generally resulted in at least 10 dB less loss at the 50 km range than did the non-positive gradient (summer) profiles.

4. Three of the areas in which propagation losses were calculated, North Sea, Strait of Juan de Fuca and Lands End, had coarse grained sediments resulting in small bottom reflection losses and relatively good propagation by bottom reflected paths. In these cases optimum propagation is in the 500 Hz frequency range.

5. Optimum frequencies of propagation for positive gradient surface ducts varied from 200 to 1000 Hz.

6. When a surface duct exists in shallow water it can dominate the propagation and lead to a completely different optimum frequency of propagation. However, to demonstrate this effect, high bottom loss is required. This is illustrated at the East of Singapore site.

7. The 500 m depth, Straits of Sicily results support the generally accepted conclusion that the optimum frequency of propagation occurs at a relatively low frequency for the case of downward refraction. However, high bottom loss is dominant in this case.

8. A change in the magnitude of the compressional wave attenuation in the sediment model produces a proportional change in the bottom reflection loss and can lead to large changes in the calculated propagation loss. This was evident in the Straits of Sicily calculations.

9. Propagation by bottom reflected paths is a very sensitive function of sediment types. Sediment models used here produced propagation ranging from very good to very poor. Many details of this propagation in the frequency domain were unexpected.

6. RECOMMENDATIONS

1. The prevalence of surface ducts in shallow water needs to be determined in many more areas.

2. The relative dominance of a surface duct when present in shallow water propagation needs further clarification.

3. Since bottom reflection loss is a large factor in shallow water propagation, the dependence of bottom loss on sediment properties, particularly attenuation, should be determined more precisely.

4. Include surface scattering in an assessment of surface duct versus bottom reflected paths.

7. REFERENCES

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APPENDIX
SHALLOW WATER ENVIRONMENTAL ANALYSIS

Introduction

Here we describe the development of data processing techniques and the subsequent analysis and summarization of sound speed data to support model studies for shallow water locations. A brief qualitative description and analysis of the seasonal sound speed structures are also provided for each of four locations.

For purposes of this study shallow water is defined in oceanographic terms as the ocean areas overlying the continental shelves. A natural break in the bottom slope near a depth of 200 m often is found marking the edge of the shelf and the beginning of the steeper continental slope. From an acoustic viewpoint, shallow water is water depths where the acoustic waves interact strongly with the ocean surface and bottom and no convergence zone paths are observed. The acoustic definition of shallow water therefore can be frequency dependent. This initial study of shallow water acoustics has been restricted to continental shelf regions at depths less than 200 m.

In our initial attempts to analyze shallow water data, we used the procedures established to select a representative sound speed profile for a particular deep open ocean environment. These did not yield results because of the extreme complexity and variability of profile shapes observed in the shallow water data samples. Because strong emphasis has been placed on the gradient of the vertical sound speed structure for acoustic purposes, analytical procedures were developed to segregate profile types based on the vertical gradient. From these subsets, representative profiles can be selected and model results evaluated on the probability of occurrence of selected profile types. For this study, profiles have been grouped objectively as positive or non-positive gradient profiles with gradient values and percentages of occurrence tabulated.

Shallow Water Environments

Four shallow water regions were selected for evaluation during this initial phase of the study. These regions were selected because they each represent a different type of shallow water environment. Specific sites were chosen because a reasonable number of observations were available to support the analysis. (For specific site locations see Figure 2.1 in the main text of this report). The Strait of Juan de Fuca off the west coast of Washington at mid latitudes represents a narrow shelf coupled strongly to the open ocean with potential brackish water influence. The shallow North Sea is an example of an isolated adjacent sea and is located at high latitudes. The area East of Singapore was selected to provide a shallow water environment to evaluate the expected weak seasonal effects at very low latitudes. The continental shelf off Lands End in the northeast Atlantic is a wide shelf at high latitudes exposed to open ocean conditions and influenced by the North Atlantic current extension of the Gulf Stream.

Method of Data Analysis

The primary source of sound speed data for this analysis was the National Oceanographic Data Center (NODC) Nansen cast archival data file. This file provides profiles of ocean temperature, salinity and computed sound speed at standard depths of 0, 10, 20, 30, 50, 75, 100, 125, 150 and 200 m. Stations with bottom depths in excess of 200 m were excluded to eliminate observations from the outer continental slope. To supplement the

number of available profiles, the NODC archival XBT file was searched for suitable temperature profiles. These profiles were then converted to equivalent sound speed profiles using annual mean salinity profiles from the Nansen cast data at each location and were interpolated for sound speed at standard depths. Even though the XBT provides less absolute temperature and resultant sound speed accuracy than the Nansen cast, blending the two profile sources is justified in this analysis because there is stronger emphasis on the statistical distribution of positive and non-positive gradients than on absolute sound speed values. The XBT data contributed significantly to the sample size for the region East of Singapore, but were not used in the North Sea where ample Nansen cast stations were available. Some additional profile editing was performed to remove redundant sampling in a few instances where repeated observations were made at the same location and time.

An initial attempt was made to classify or "pigeonhole" profiles by vertical shape or type. This process is impractical because it requires the selection criteria to be redefined for each data set and because there are few guidelines for acoustic significance of the various sound speed structures. The overall sound speed gradient computed from the surface to specified depths is of basic acoustic significance in defining the expected mode of propagation, therefore, a statistical approach to gradient distributions was applied to the data. Surface energy exchange (i.e., heat and wind) and horizontal and vertical advection can affect the vertical sound speed gradient. The presence of the sea floor influences advection, and, therefore, can also influence the gradient. To avoid biasing the statistics, shallow profiles that covered less than 80 percent of the water column were eliminated in all instances except in the region East of Singapore because of the limited number of observations. Deep profiles would be expected to display any bottom-related effects.

Two methods of statistical tabulation were used for the vertical sound speed gradients. Examples of each are provided in the individual site analyses in the following section of this Appendix. Gradients are computed in units of meters/second per meter. The first approach produced a tabular listing by season of the number of positive and non-positive gradients observed in the data set from the surface to each successive standard depth. It also provided statistics on gradient strengths. These tables provided information on whether the overall gradients were positive or non-positive and some measure of correlation between gradient and depth of observations. However, because the identity of individual profiles is lost in this statistical summary, it is not an adequate guide to the selection of representative profiles for acoustic model inputs.

The second statistical approach preserves the identity of each profile while providing a measure of the distribution of positive and non-positive sound speed gradients. Many profiles in complex shallow water environments may contain both positive and negative gradient layers at different depths in the water column. This is especially noticeable during the spring and fall transition seasons. To classify a single profile as either a positive or non-positive gradient profile requires a definition based on the expected effect of the overall shape on the primary mode of acoustic propagation. The definition also must remain relatively simple if it is to be applicable to all shallow water environments. The basic definition chosen for this analysis will classify a profile as positive if the depth of the absolute maximum observed sound speed value is greater than 10 m, and non-positive if the absolute maximum is observed within 10 m of the surface. This allows a rather large number of possible profile shapes to be grouped together in either category. However, as a first order profile type separator for an assumed near surface sound source, this sorting approach works well.

Additional statistics are computed to provide information on the strength of the observed gradients. For positive profiles the gradient is computed and tabulated from the absolute sound speed maximum to the shallower sound speed minimum. For non-positive profiles the gradient is computed from the near surface maximum to the deeper absolute minimum. If the profile has a deeper positive gradient leg below the absolute minimum, this value is also computed. Examples of possible positive and non-positive gradient profile types are shown in Figure 23 of the main body of this report. With this statistical summary, it is possible for the investigator to determine how many profile types are necessary to represent adequately the particular shallow water site and season. With the aid of the gradient strength and depth information, suitable representative profiles may be selected from the individual data subsets for acoustic model inputs.

Discussion of Selected Shallow Water Environments

This initial investigation for four selected shallow water sites confirms the suspicion that shallow water environments tend to be complex, highly variable and generally cannot be summarized by the same analysis techniques applicable to deep open ocean waters. Although each of the four selected shallow water regions displays unique environmental characteristics, we can draw some tentative general conclusions concerning the distribution of vertical sound speed structures.

Vertical sound speed characteristics for the winter season in mid and high latitudes can be summarized reasonably well in terms of basic structure. Winter mixing and surface heat losses normally produce a near-isothermal water column and result in a slightly positive sound speed gradient from the surface to the bottom. The single equatorial site sampled East of Singapore also indicated a tendency for this environment to produce this positive gradient profile in winter and to some extent in summer. The absolute sound speeds, of course, vary significantly with location (and latitude).

The summer season indicates some consistency in overall sound speed gradient for the different locations. With the exception of a potential shallow mixed layer (surface duct), the summer profiles usually have negative gradients to the bottom. The actual shapes of the profiles, however, may vary considerably at a given site. The North Sea provides an example of two distinctly different vertical structures observed in the summer.

The spring and fall are transition seasons where both positive and negative profile gradients are observed. Based on the sites evaluated, it appears that the high latitude and mid latitude transition months show a preponderance of negative gradients. The fall appears to have deeper positive gradient surface ducts than the spring. The low latitudes (based on the single equatorial example) tend to display relatively more positive gradients throughout the year.

These tentative conclusions are based primarily on reasonable and general effects expected from seasonal surface heat exchange and vertical mixing. The presence of nearby land masses and the influence of the bottom itself make most shallow water environments subject to strong advecture perturbations. This movement of water masses can modify or dominate the more classical seasonal effects on the vertical structure of temperature and salinity. Results from this limited shallow water study should be applied very cautiously to other apparently similar locations.

The following discussions present specific information and examples of shallow water sound speed variability and vertical gradient statistics for four selected sites. This type of summary has been provided to support initial acoustic studies of shallow water environments described in the main body of this report. Based on an evaluation of these environmental summaries, this approach to sound speed profile classification and selection can be modified or expanded for follow-on analyses of other shallow water environments.

The data presentation for each site consists in part of certain summaries and displays originally created for deep ocean analysis. These include the temperature-salinity-sound speed statistical summary tables at standard depths, the composite profile plots for sound speed which superimpose all profiles for a given site/season on a single plot and the temperature-salinity (T-S) diagrams with sigma-T (density related) curves. A single sound speed range and depth were selected for all composite plots to facilitate an intercomparison of the different site environments. In addition, two statistical summaries are presented that were specifically developed for the analysis of shallow water sound speed data. The shallow water sound speed statistical summary provides some information on percentage of water column coverage. Of more significance is the lower portion of this table where the surface-to-standard-depth sound speed gradients are tabulated. The shallow water profile gradient summary table provides the information necessary to evaluate the distribution of profile types for each site/season and aid in the final selection of profiles for acoustic model inputs. The presentations and discussions of specific model input data are contained in the main body of this report.

NORTH SEA

This location provides a good example of an isolated adjacent sea that has limited communication with the open ocean as well as high latitude seasonal variations. Data were processed and analyzed by the standard three-month seasons of winter (January–March), spring (April–June), summer (July–September) and fall (October–December). Figures containing statistical summaries, gradient statistics, composite plots and T–S plots are ordered by season at the end of the discussion.

Winter Essentially all profiles have positive sound speed gradients from the surface to the bottom of the profile. This is the result of total vertical mixing and isothermal conditions surface to bottom. The only profile differences are year to year and January-to-March shifts in the absolute values. The highest sound speeds appear in early January and the lowest, in late March. These comments are restricted to the 1° x 1 1½° site analyzed; however, we presume these variations are reasonably consistent in the central North Sea. The selection of a single typical profile for acoustic purposes is reasonable because the overall positive gradients were observed to be consistent. The extent of homogeneity and weak stability created by winter mixing is evident by the low individual profile temperature and salinity ranges exhibited on the winter T–S diagram.

Spring – Three basic profile types are evident during spring. The positive gradient profiles are observed primarily in early April during some years and are remnants of the winter profile type, prior to the onset of spring warming. About 33 percent of the profiles are classified as positive gradient. Two other basic profile types have been observed:

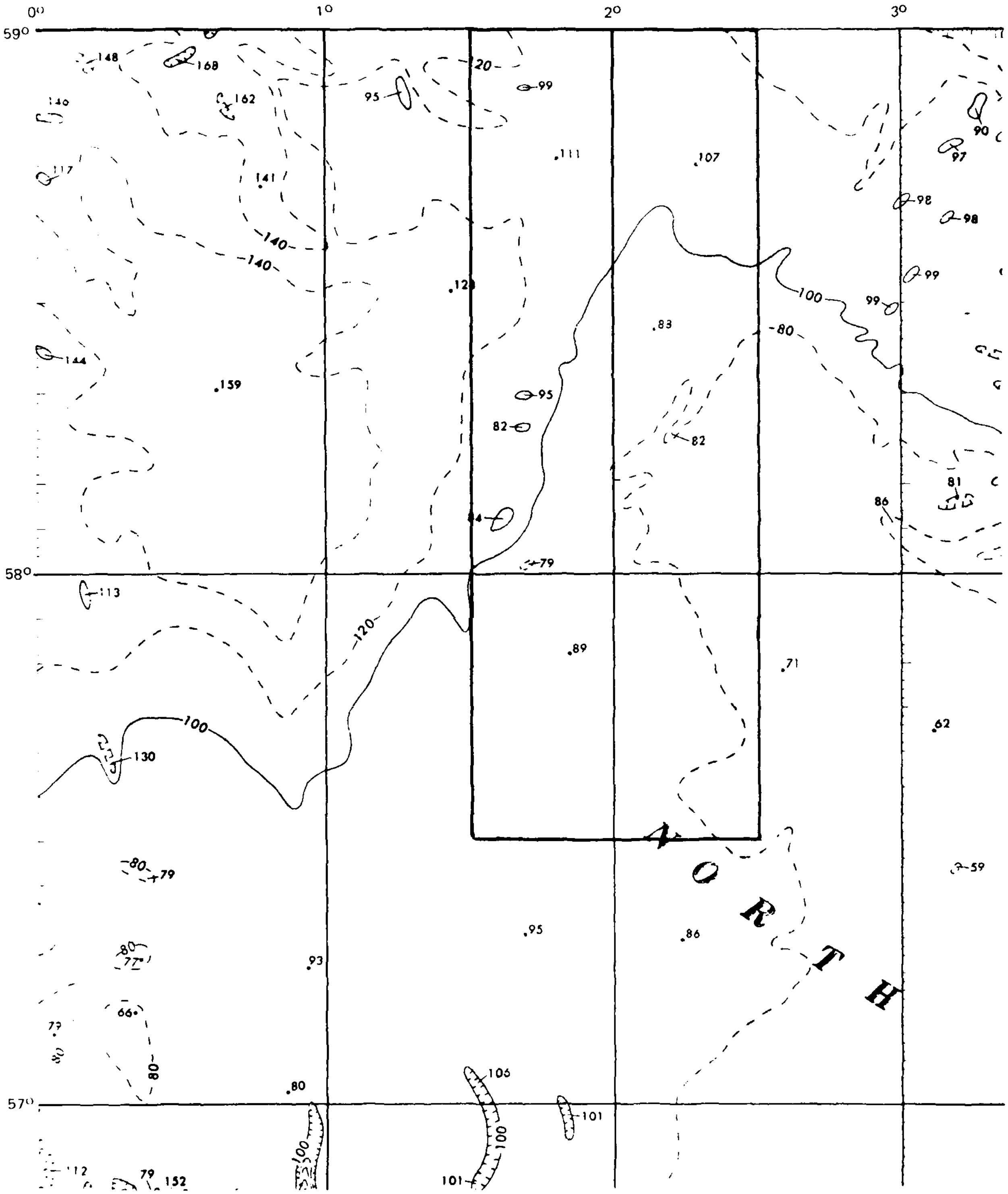
- Type I has sharp negative gradients indicated to 75 m, some with a shallow mixed layer. Below 75 m a weak positive gradient extends to the profile bottom with a slope similar to the deep winter profiles. More than 50 percent of the profiles have a sound speed minimum at 50 m to 75 m.
- Type II has weak near-surface gradients that may be positive or negative with somewhat negative gradients below 30–50 m. Bottom sound speeds are near winter values.

Type I profiles appear to represent the expected effect of increasing surface heat exchange during spring warming. The dominance of the strong temperature gradient on the resultant sound speed structure and increased stability of the water column is clearly shown on the T–S diagram. Type II profiles seem to be influenced by positive heat advection in addition to the surface warming. A more extensive study of North Sea oceanography would have to be made to establish explanations for the two separate profile types. It would be possible to select three typical profile types to represent the spring. However, it is not possible from this analysis to predict the occurrence of Type I or Type II

Summer These data indicate the presence of the same basic Type I and Type II profiles observed during spring. The remnant winter positive profiles are gone. However, 24 percent of the profiles are still classified as positive because of the depth of the surface layer. The difference between Type I and Type II profiles seems more pronounced. Most of the Type I profiles have a surface layer to 20–30 m and a strong negative gradient to 75 m. Some have a sound speed minimum at 75–100 m and a weak positive gradient to the bottom. The Type II profiles usually have negative sound speed gradients from surface to bottom with little or no surface layer. The slope is nearly linear or increases slightly with depth. The T–S diagram indicates that the structure is primarily temperature controlled with a few instances of surface layer salinity dilution. Water column stability is

very high. The two basic types could be separated for the selection of typical profiles; however, the key to the advance prediction of the occurrence of either type is not apparent from this analysis.

Fall – This season again indicates the presence of the thr   profile types observed during the spring. However, Type I has a deeper surface layer extending to 50 m or more and a correspondingly thinner thermocline layer. The occurrence of deep surface layers results in the classification of 92 percent of the profiles as positive gradient. The winter-type positive gradient profiles are observed only during late November and December. Based on the sound speed gradient statistics, more than one-half of the fall profiles extending past 50 m have an overall negative gradient when measured from the surface. This is caused by the predominantly negative gradient observed below 50 m. The separation of profile types and the selection of typical profiles for the fall is difficult because the distinction between the types is less clear than during the summer.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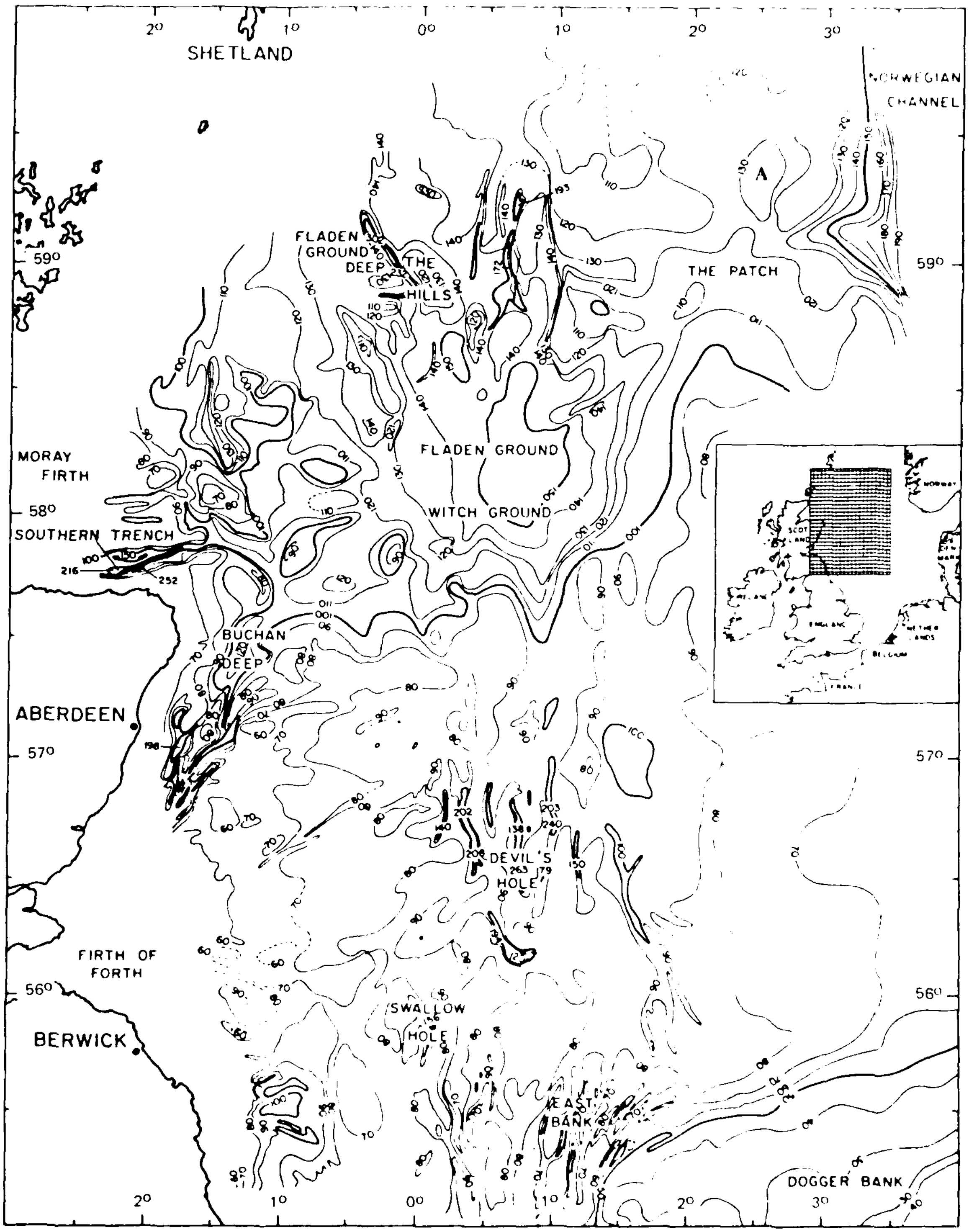
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NORWEGIAN CHANNEL
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WITCH GROUND
SOUTHERN TRENCH
BUCHAN DEEP
ABERDEEN
DEVIL'S HOLE
FIRTH OF FORTH
SWALLOW HOLE
BERWICK
EAST BANK
DOGGER BANK
59°
58°
57°
56°

NORTH SEA - WINTERS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	8.32	6.40	4.82	.7334	35.23	35.13	34.96	.0612	1484.2	1476.83	1470.2	2.9331	109
10	8.37	6.42	4.62	.7338	35.23	35.13	34.96	.0570	1484.3	1476.97	1470.5	2.9314	109
20	8.34	6.40	4.63	.7402	35.25	35.13	34.96	.0580	1484.5	1477.11	1470.6	2.9669	109
30	8.34	6.38	4.64	.7484	35.23	35.13	34.96	.0571	1484.7	1477.23	1470.6	2.9953	109
50	8.36	6.36	4.75	.7651	35.25	35.13	34.95	.0581	1485.1	1477.46	1470.7	3.0695	109
75	8.39	6.08	4.60	.8206	35.26	35.11	34.95	.0724	1485.6	1476.73	1470.8	3.2967	51
100	7.18	6.33	5.20	.5469	35.23	35.10	34.94	.0879	1481.6	1478.18	1473.5	2.2339	13
125	6.36	6.36	6.36	.0000	35.16	35.16	35.16	.0000	1478.8	1478.80	1478.8	.0000	1

SHALLOW WATER PROFILE GRADIENT SUMMARY

NORTH SEA - WINTER
TOTAL OBS 109

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	2	1.8	1.8	.010	.050	.090	.057	1480.2	1481.2	76.0	6.
30	4	3.7	5.5	.007	.014	.020	.006	1473.9	1474.3	78.7	8.
50	55	50.5	56.0	.008	.018	.032	.006	1477.5	1478.3	73.2	2.
75	29	26.6	82.6	.007	.016	.027	.005	1475.9	1477.0	86.4	6.
100	12	11.0	93.6	.003	.015	.024	.007	1476.6	1478.2	110.7	7.
125	1	.9	94.5	.020	.020	.020	.000	1476.3	1478.8	.0	0.
TOTAL	103										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	MEAN	MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	MEAN	MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	0																
50	0																
75	6	5.5	5.5	.008	.030	.055	.018										
TOTAL	6														1476.3	1474.0	84.3

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 6, 100.0 PCT OF THE NEG GRAD OBS.

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

NORTH SEA - WINTER

TOTAL NO. OF OBS: 109
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 107
MAX: 124 MEAN: 81.7 MIN: 71

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	58	70.4	68.5	62.5
75	37	97.4	87.5	75.0
100	12	99.0	90.7	80.6
125	0	.0	.0	.0
150	0	.0	.0	.0
200	0	.0	.0	.0

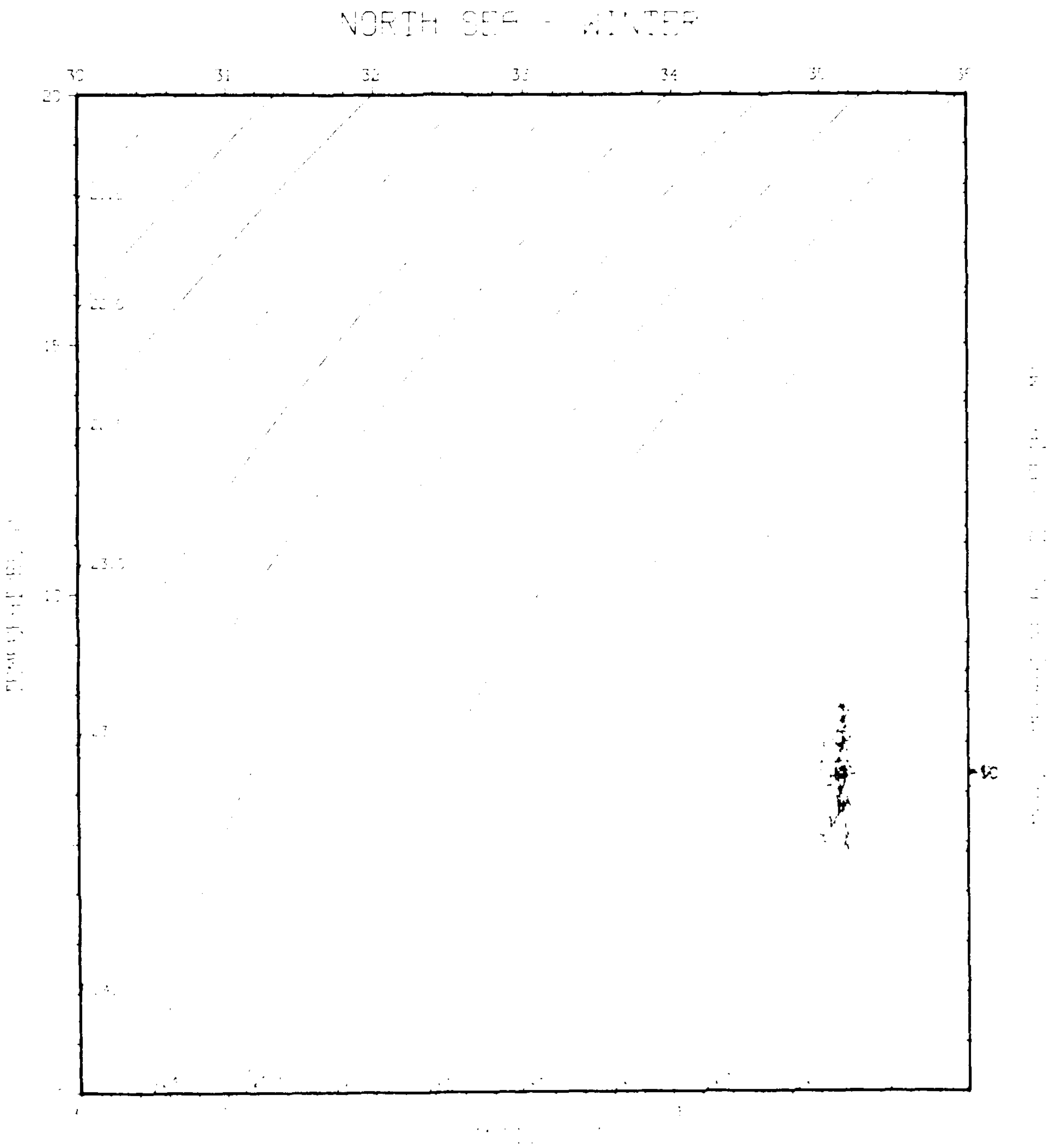
SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

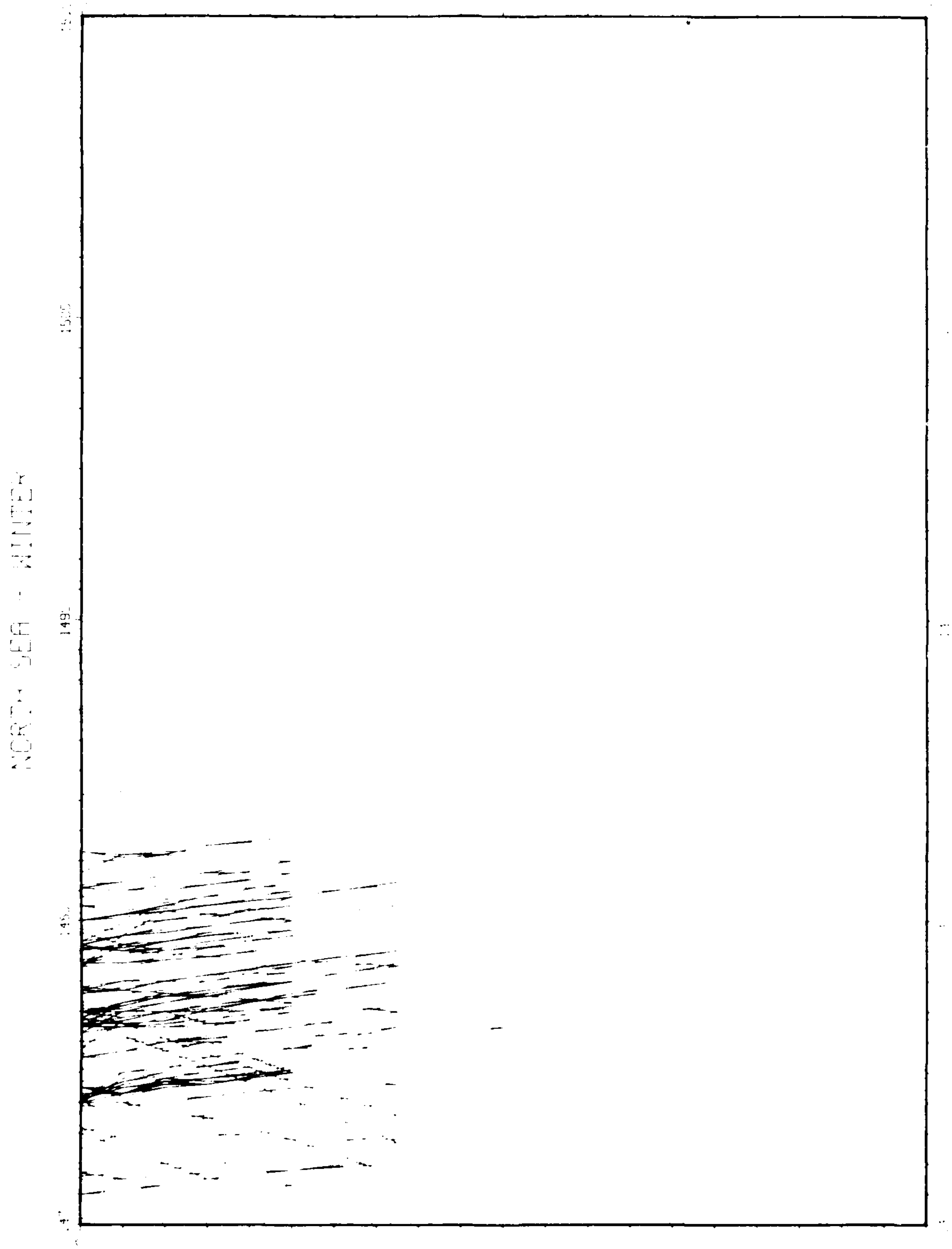
	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	89	81.7	.090	.021	.005	.0143	12	11.0	.055	.024	.005	.0186	8	7.3
30	95	87.2	.057	.018	.003	.0094	10	9.2	.053	.023	.003	.0191	4	3.7
50	98	89.9	.034	.016	.002	.0070	10	9.2	.054	.020	.002	.0189	1	.9
75	44	86.3	.027	.014	.003	.0071	7	13.7	.055	.026	.008	.0177	0	.0
100	13	100.0	.024	.016	.003	.0067	0	.0	.000	.000	.000	.0000	0	.0
125	1	100.0	.020	.020	.020	.0000	0	.0	.000	.000	.000	.0000	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

*XBT GRAD.ABS
107

13	17	30	31	77	78	79	91	92	113	121	122	131	171	187	196
197	198	212	213	236	255	256	264	265	266	281	314	315	316	317	318
319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334
335	336	337	338	339	340	341	342	343	344	377	378	379	380	381	382
383	384	386	387	388	389	390	391	392	393	394	395	396	397	398	399
400	401	426	450	451	472	473	485	490	494	500	517	518	539	543	558
561	569	571	573	591	593	594									

*
165 227 456 457 542 557


NORTH SEA - WINTER


NORTH SEA - WINTER

NORTH SEA - SPRINGS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	13.40	8.59	5.00	2.1089	35.33	35.01	34.35	.1248	1502.3	1484.95	1470.8	7.8574	193
10	13.51	8.32	4.72	1.9459	35.32	35.01	34.69	.1116	1502.9	1484.13	1470.0	7.2690	193
20	11.07	7.87	4.70	1.6029	35.27	35.02	34.76	.1056	1497.5	1482.42	1470.0	6.0607	193
30	11.40	7.48	4.69	1.3957	35.25	35.03	34.77	.1046	1496.0	1481.34	1470.1	5.3171	193
50	10.21	6.80	4.57	1.0758	35.30	35.05	34.78	.1028	1492.0	1479.07	1470.0	4.1647	193
75	9.38	6.46	4.01	.7862	35.32	35.07	34.76	.1004	1489.3	1478.20	1470.7	3.1105	177
100	8.01	6.48	5.26	.5564	35.35	35.13	34.89	.1085	1484.7	1477.78	1473.7	2.2305	65
125	6.72	6.45	5.78	.4561	35.30	35.15	34.89	.1926	1480.6	1479.10	1476.5	1.7944	4

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

NORTH SEA - SPRING

TOTAL NO. OF OBS: 193 — NO. OF OBS WITH RECORDED BOTTOM DEPTH: 187

PROFILES REJECTED (TOO DEEP): 0 — MAX: 154 MEAN: 96.0 MIN: 66

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	16	75.8	65.1	48.1
75	108	100.0	85.1	69.4
100	59	98.0	89.8	64.9
125	4	98.4	97.5	96.2
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	51	26.4	.150	.020	.005	.0210	131	67.9	.875	.179	.005	.1861	11	5.7
30	48	24.9	.100	.017	.003	.0150	142	73.6	.733	.169	.003	.1695	3	1.6
50	45	23.3	.060	.015	.002	.0104	147	76.2	.564	.159	.002	.1357	1	.5
75	43	22.3	.047	.014	.001	.0096	135	76.3	.387	.120	.001	.0890	2	1.1
100	24	36.9	.037	.014	.002	.0092	40	61.5	.265	.099	.005	.0621	1	1.5
125	0	.0	.000	.000	.000	.0000	4	100.0	.144	.126	.097	.0216	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

*XBT GRAD.ABS

64															
2	9	14	22	29	41	42	43	50	53	59	62	71	80	82	93
95	104	106	114	115	127	128	131	132	133	134	135	159	160	169	173	174
175	177	178	179	181	182	191	192	201	214	228	257	258	267	273	274
275	276	422	430	431	443	445	449	458	459	474	496	537	540	544	545
129															
1	8	18	21	23	28	32	35	37	46	48	55	58	63	69	70
72	73	75	76	81	83	84	85	94	96	97	98	99	105	107	108
109	110	111	112	117	136	137	138	142	152	153	154	155	166	167	172
180	183	188	189	190	199	200	202	203	204	215	216	217	218	219	220
229	237	238	245	246	259	260	268	271	272	277	278	345	346	402	407
415	418	429	433	434	435	437	438	439	440	441	442	452	460	465	466
467	468	475	476	479	480	487	498	499	504	519	521	522	524	527	529
531	533	534	535	536	541	546	551	552	553	554	565	570	574	580	581
592															

SHALLOW WATER PROFILE GRADIENT SUMMARY

NORTH SEA - SPRING
TOTAL OBS 193

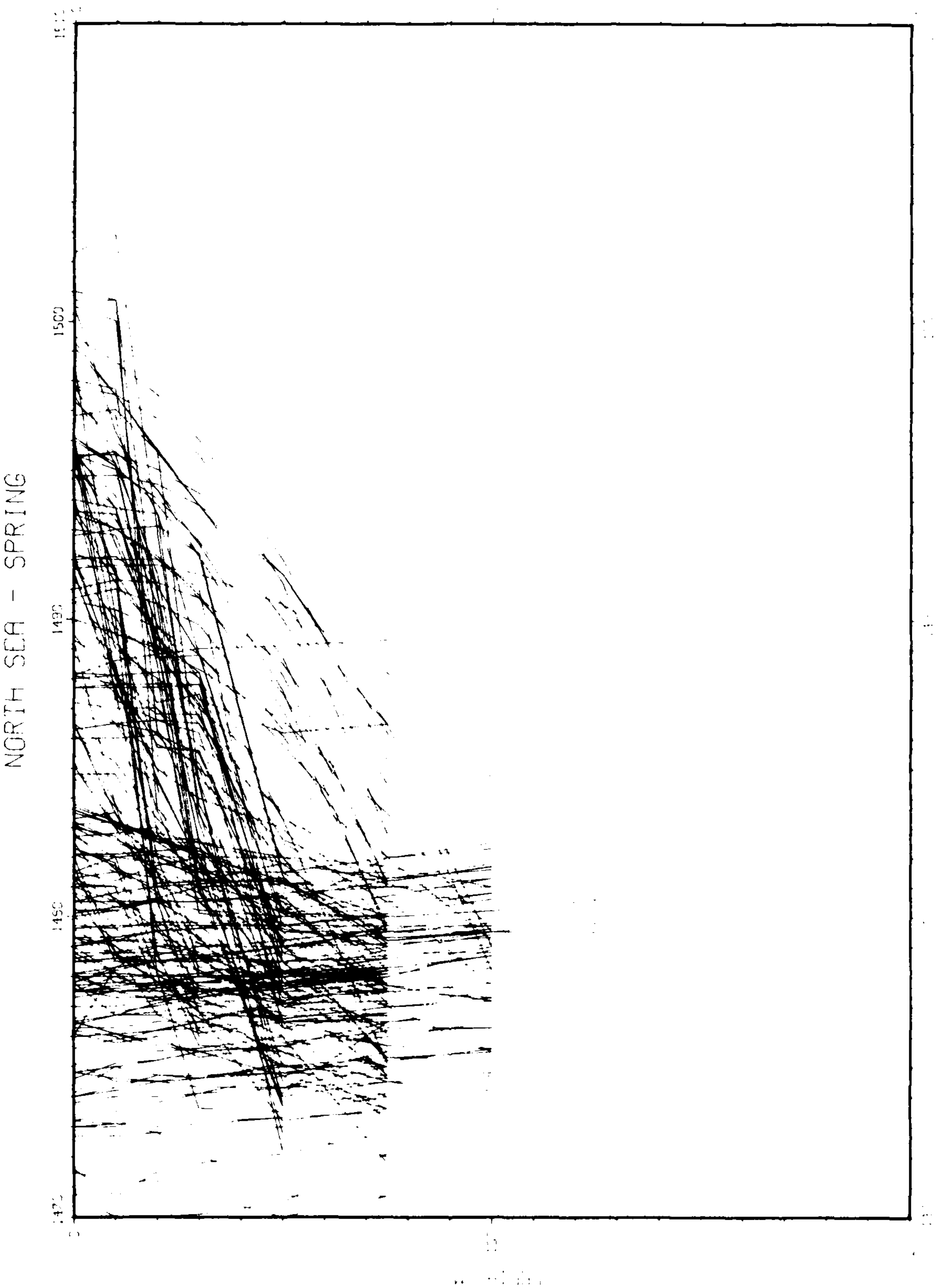
POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

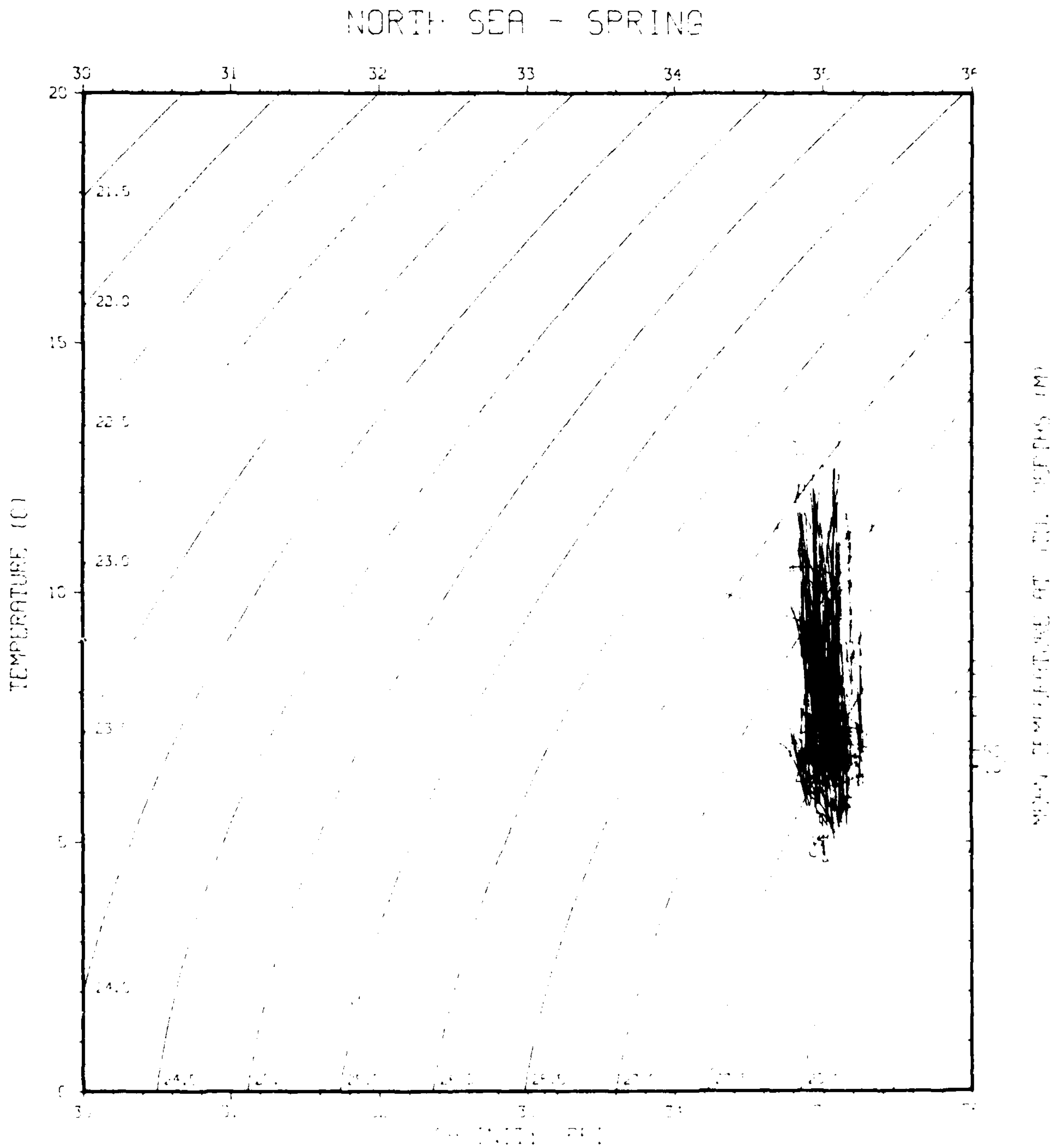
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	11	5.7	5.7	.000	.009	.030	.009	1483.6	1483.7	99.9	24.
30	5	2.6	8.3	.003	.006	.007	.001	1483.3	1483.4	98.8	6.
50	10	5.2	13.5	.010	.016	.022	.005	1478.6	1479.2	92.1	17.
75	19	9.8	23.3	.001	.016	.032	.009	1476.9	1477.8	86.2	7.
100	19	9.8	33.2	.007	.018	.037	.008	1476.8	1478.5	110.8	5.
TOTAL	64										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	GRADIENT TO SURFACE STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	GRADIENT BELOW MIN STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	1	.5	.5	.000	.000	.000	.000	1	.5	.5	.090	.090	.090	.000	1474.1	1474.1	110.0
10	0																
20	1	.5	1.0	.050	.050	.050	.000	1	.5	1.0	.009	.009	.009	.000	1478.7	1477.7	.0
30	3	1.6	2.6	.020	.106	.197	.068	3	1.6	2.6	.009	.012	.016	.003	1480.3	1477.1	88.0
50	47	24.4	26.9	.014	.212	.534	.153	36	18.7	21.2	.004	.017	.058	.010	1487.7	1477.2	89.2
75	64	33.2	60.1	.013	.140	.367	.089	12	6.2	27.5	.004	.011	.020	.005	1488.6	1476.4	94.8
100	12	6.2	66.3	.032	.114	.181	.056								1489.0	1477.6	113.0
125	1	.5	66.8	.141	.141	.141	.000								1494.1	1476.5	128.0
TOTAL	129																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 76. 58.9 PCT OF THE NEG GRAD OBS.


NORTH SEA - SPRING


NORTH SEA - SPRING
TEMPERATURE (C)
21.5
22.0
23.0
30
31
32
33
34
20
15
10
5

NORTH SEA - SUMMERS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	16.29	13.66	10.01	1.2650	35.33	34.84	31.76	.4306	1511.0	1502.77	1490.2	4.2383	173
10	16.04	13.37	10.01	1.3339	35.26	34.86	32.51	.3611	1510.5	1501.97	1490.3	4.4566	173
20	15.89	12.63	9.39	1.4192	35.31	34.92	33.16	.2584	1510.5	1500.38	1487.8	4.7837	173
30	15.71	11.48	5.26	1.7456	35.25	34.99	34.47	.1275	1510.1	1495.99	1472.6	6.0856	173
50	12.59	8.45	5.28	1.7107	35.40	35.03	34.31	.1281	1500.1	1485.34	1473.0	6.4033	173
75	10.13	7.35	5.28	.9491	35.25	35.06	34.14	.1187	1492.3	1481.68	1473.5	3.5951	159
100	8.67	7.11	6.00	.5779	35.29	35.10	34.83	.1104	1487.3	1481.20	1476.7	2.3327	46
125	6.80	6.25	5.71	.7707	35.23	35.07	34.92	.2192	1480.6	1478.20	1475.8	3.3941	2

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

NORTH SEA - SUMMER

TOTAL NO. OF OBS: 173
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 166
MAX: 145 MEAN: 93.8 MIN: 68

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	13	73.5	61.9	46.3
75	110	98.7	86.0	69.4
100	42	99.0	89.6	82.6
125	1	86.2	86.2	86.2
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	40	23.1	.185	.025	.005	.0330	125	72.3	.780	.173	.005	.1263	8	4.6
30	19	11.0	.160	.026	.007	.0411	153	88.4	1.073	.259	.003	.1986	1	.6
50	2	1.2	.012	.011	.010	.0014	171	98.8	.710	.353	.016	.1525	0	.0
75	0	.0	.000	.000	.000	.0000	159	100.0	.467	.283	.060	.0757	0	.0
100	0	.0	.000	.000	.000	.0000	46	100.0	.299	.211	.095	.0459	0	.0
125	0	.0	.000	.000	.000	.0000	2	100.0	.202	.156	.115	.0611	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

BXGT GRAD.AES

42

10	11	16	25	39	45	51	52	56	57	130	144	147	150	164	168
164	166	225	231	234	275	247	261	269	279	350	405	406	410	413	419
424	501	527	528	530	575	576	577	587	588						

171

3	5	19	20	24	33	34	36	38	40	47	49	54	60	61	64
65	66	67	68	86	87	88	89	90	100	101	102	103	118	119	120
123	124	125	126	129	140	143	145	146	149	151	156	161	162	163	170
174	205	206	207	208	209	210	211	221	222	223	224	226	230	232	233
239	240	241	249	251	252	253	254	262	270	280	282	283	347	348	351
407	409	412	414	423	424	425	427	432	446	447	453	454	455	461	462
467	464	469	470	471	477	478	481	482	483	495	497	502	505	506	511
513	514	515	525	572	547	548	549	550	555	556	559	560	566	572	578
579	553	565													

SHALLOW WATER PROFILE GRADIENT SUMMARY

NORTH SEA - SUMMER
TOTAL OBS 173

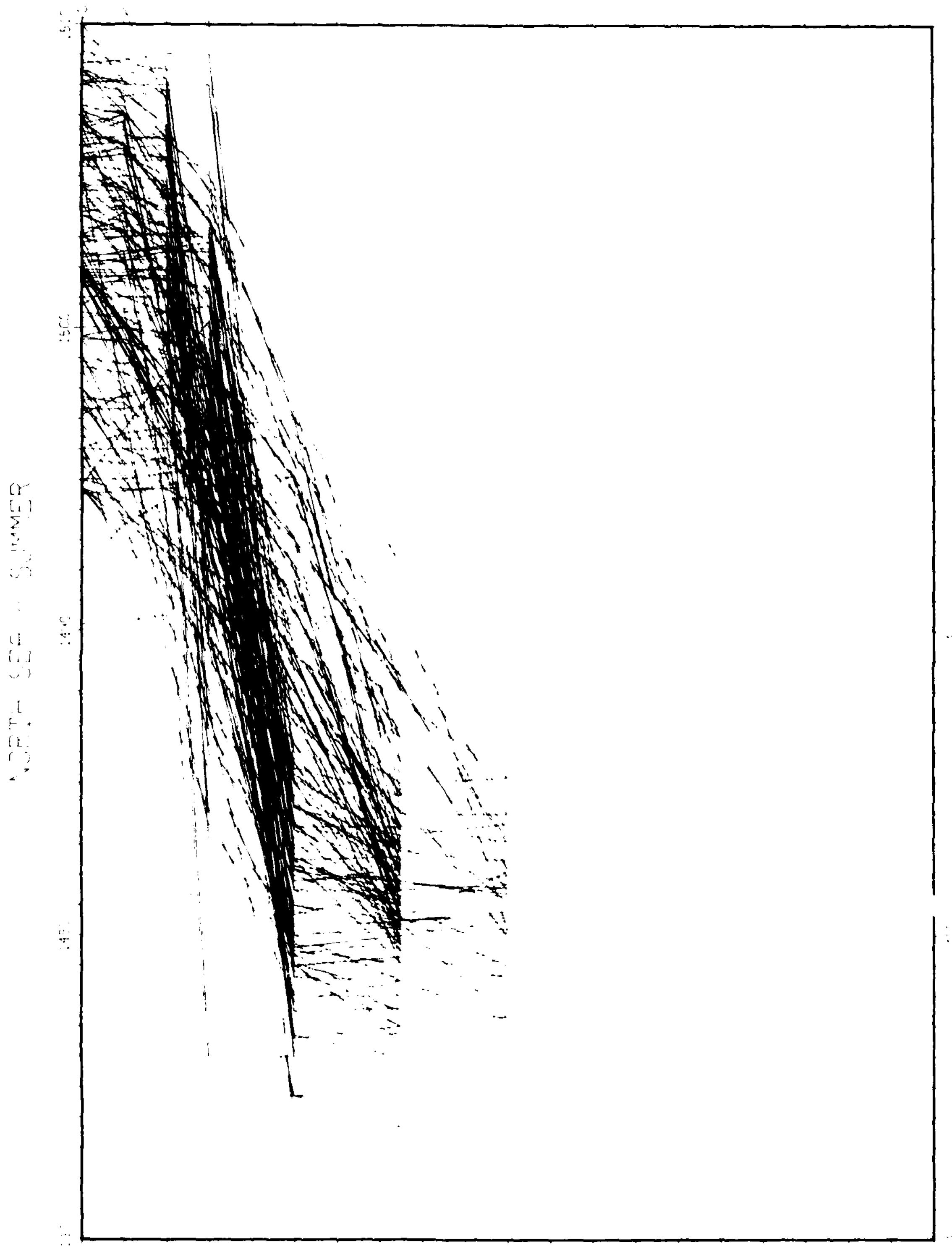
POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

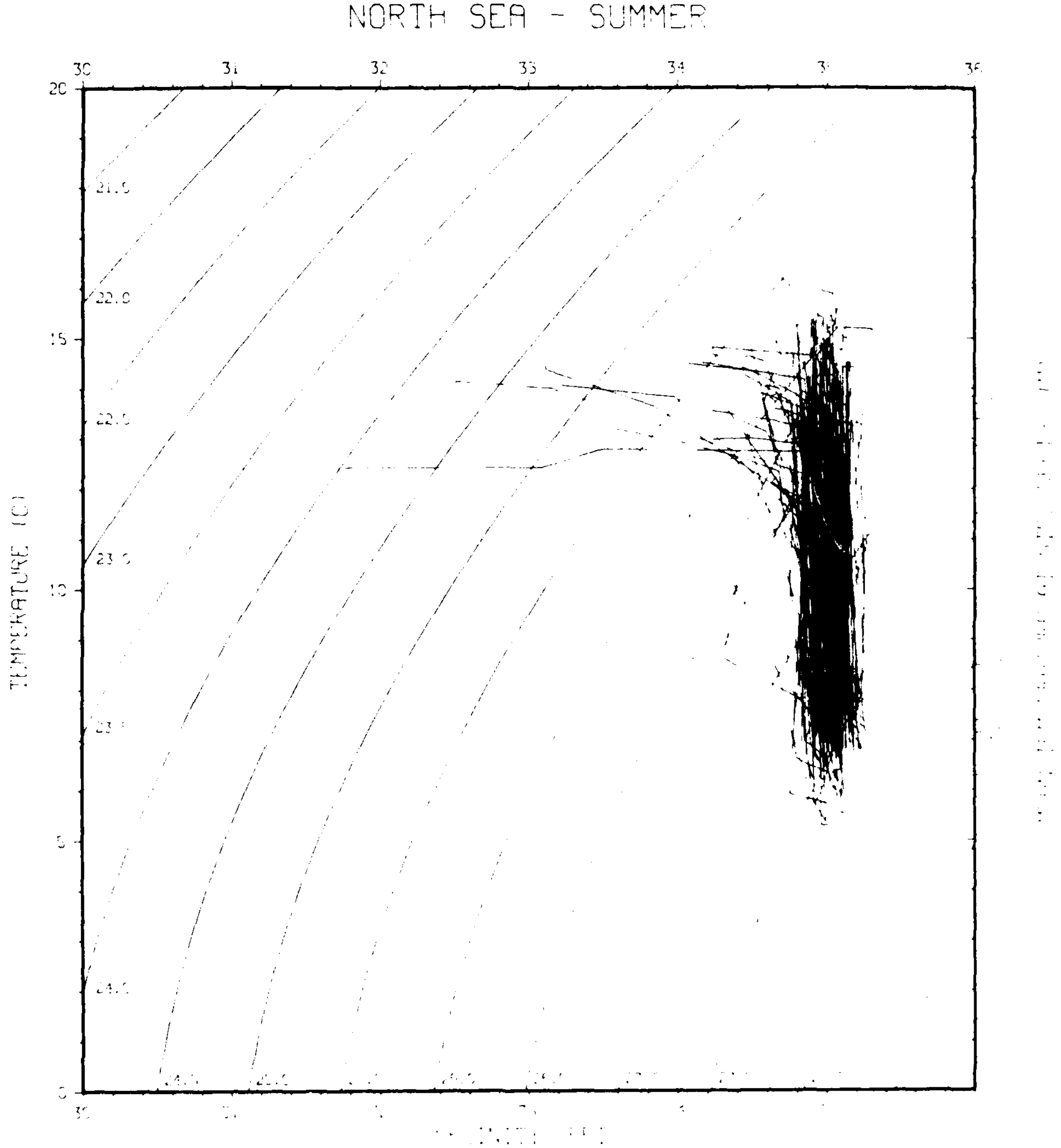
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	24	13.9	13.9	.000	.019	.070	.017	1502.2	1502.6	90.4	13.
30	16	9.2	23.1	.007	.030	.180	.044	1500.5	1501.4	94.9	15.
50	2	1.2	24.3	.010	.011	.012	.001	1495.2	1495.8	.0	0.
TOTAL	42										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	1	.6	.6	.973	.973	.973	.000	1	.6	.6	.020	.020	.020	.000	1501.8	1472.6	79.0
50	22	12.7	13.3	.330	.495	.640	.078	15	8.7	9.2	.004	.013	.032	.007	1504.1	1479.3	78.9
75	82	47.4	60.7	.109	.284	.433	.066	8	4.6	13.9	.004	.014	.060	.019	1503.2	1481.9	90.0
100	25	14.5	75.1	.095	.212	.299	.052	1	.6	14.5	.016	.016	.016	.000	1502.8	1481.6	114.0
125	1	.6	75.7	.202	.202	.202	.000								1501.0	1475.8	-1.0
TOTAL	131																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 106. 80.9 PCT OF THE NEG GRAD OBS.





NORTH SEA - SUMMER
30
31
32
33
34
36
20
15
10
5
0
21.5
22.0
23.0
24.0
TEMPERATURE (C)

NORTH SEA - FALL9

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	12.04	9.48	7.79	1.1163	35.27	35.11	34.63	.0936	1497.7	1488.53	1482.2	4.0274	89
10	12.00	9.47	7.83	1.1026	35.26	35.10	34.76	.0801	1497.7	1488.68	1482.5	3.9782	89
20	12.00	9.46	7.61	1.1064	35.20	35.10	34.76	.0771	1496.0	1488.79	1482.0	4.0019	89
30	12.00	9.44	7.37	1.1065	35.23	35.11	34.76	.0777	1496.0	1488.89	1481.1	4.0079	89
50	11.75	9.02	6.30	1.1230	35.25	35.11	34.86	.0699	1497.3	1487.64	1477.2	4.1602	89
75	9.98	8.06	6.28	.8987	35.26	35.11	34.98	.0722	1491.8	1484.46	1477.6	3.4569	33
100	8.96	7.60	6.39	1.0169	35.27	35.12	35.06	.0806	1486.3	1483.16	1478.7	3.8505	7

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

NORTH SEA - FALL

TOTAL NO. OF OBS: 89
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 69
MAX: 120 MEAN: 79.8 MIN: 69

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	56	72.5	68.3	67.6
75	26	100.0	88.5	76.5
100	7	95.2	88.7	83.3
125	0	.0	.0	.0
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	79	88.8	.060	.022	.005	.0125	9	10.1	.105	.062	.005	.0399	1	1.1
30	79	88.8	.053	.020	.007	.0101	7	7.9	.103	.077	.010	.0325	3	3.4
50	65	73.0	.042	.018	.002	.0078	23	25.8	.304	.120	.002	.1037	1	1.1
75	15	45.5	.035	.019	.004	.0093	18	54.5	.241	.107	.001	.0606	0	.0
100	2	28.6	.034	.026	.017	.0120	5	71.4	.177	.074	.007	.0628	0	.0
125	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

•XGT GRAD.APS

62

4	6	7	12	139	157	158	242	243	244	249	263	264	285	286	287
288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303
304	305	306	307	308	309	310	311	312	313	352	353	354	355	356	357
358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373
374	375	376	416	421	436	444	448	464	492	493	516	526	563	566	589
590	591														

7

250	420	488	489	564	567	568

SHALLOW WATER PROFILE GRADIENT SUMMARY

NORTH SEA - FALL
TOTAL OBS 89

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	1	1.1	1.1	.025	.025	.025	.000	1495.1	1495.6	67.0	0.
30	18	20.2	21.3	.010	.016	.025	.005	1492.7	1493.2	79.7	11.
50	50	56.2	77.5	.002	.018	.036	.006	1487.8	1488.7	76.2	10.
75	11	12.4	89.9	.009	.019	.033	.008	1485.1	1486.5	84.6	8.
100	2	2.2	92.1	.017	.026	.034	.012	1485.3	1487.8	118.0	3.
TOTAL	82										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	MEAN	MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	MEAN	MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	1	1.1	1.1	.010	.010	.010	.000	1	1.1	1.1	.004	.004	.004	.000	1485.7	1485.0	90.0
50	0																
75	6	6.7	7.9	.064	.089	.108	.016								1488.9	1492.2	85.8
TOTAL	7																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 6, 85.7 PCT OF THE NEG GRAD OBS.

AD-A116 041 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 8/10
EVALUATION OF SURFACE DUCTS IN SHALLOW WATER.(U)
MAR 82 J A WHITNEY, D F GORDON, J G COLBORN
UNCLASSIFIED NOSC/TR-763 NL

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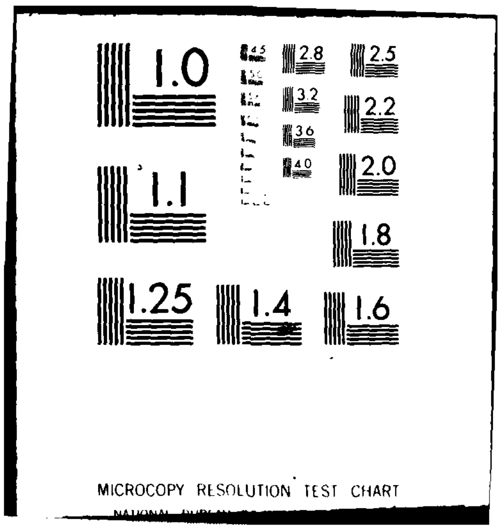
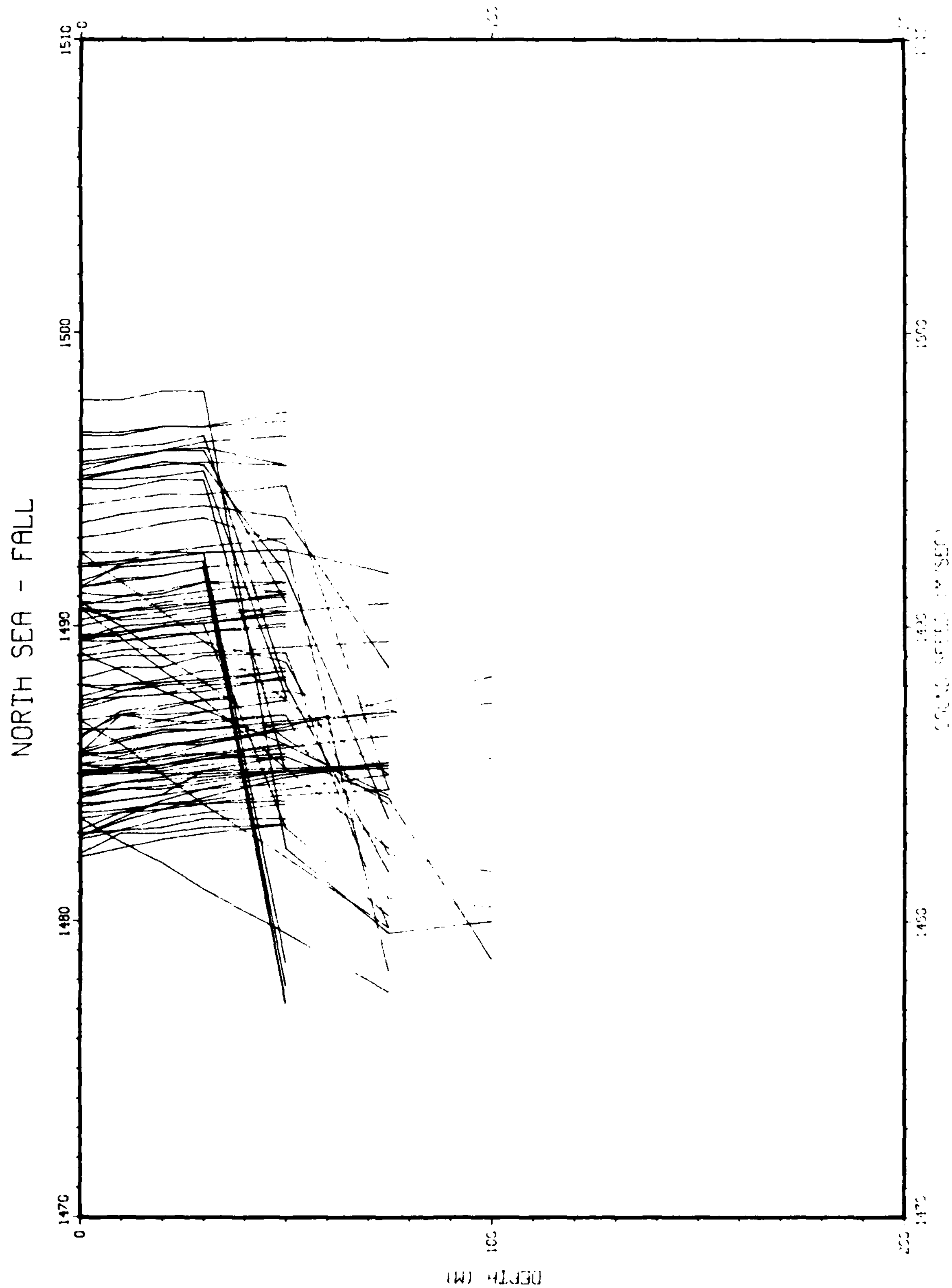
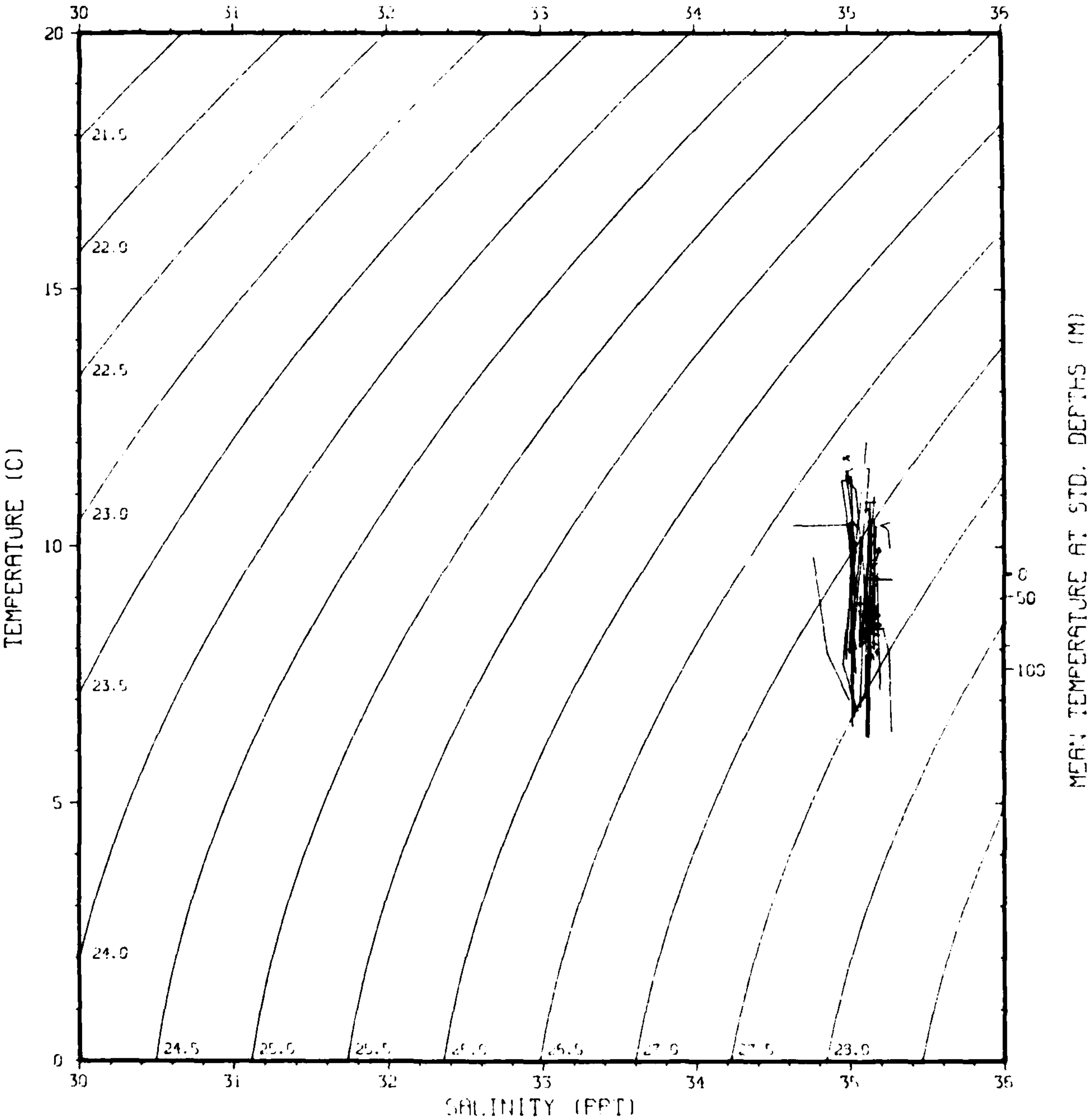

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART


NORTH SEA - FALL
1510
1500
1490
1480
1470
0
DEPTH (M)

NORTH SEA - FALL



STRAIT OF JUAN DE FUCA

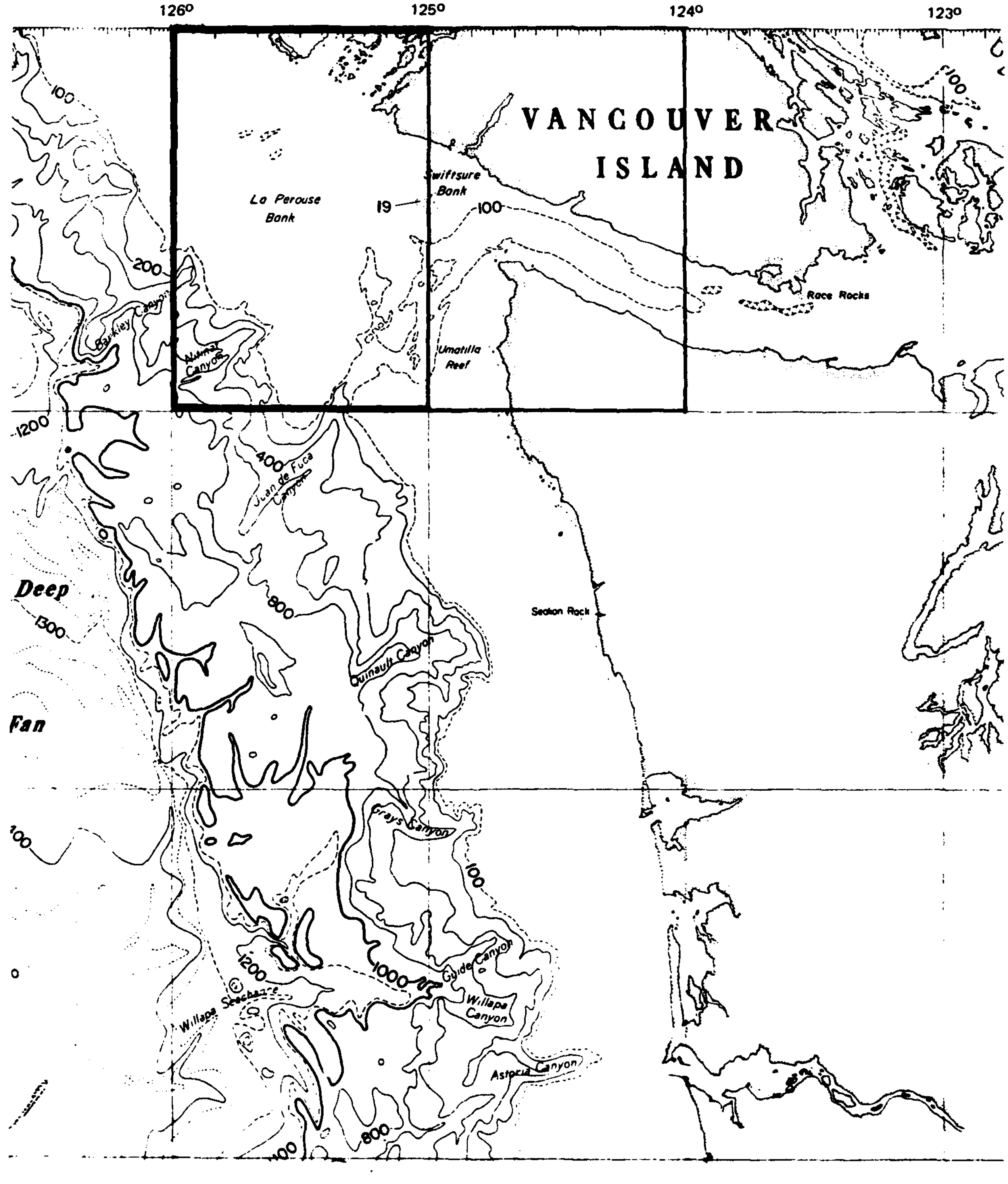
This shallow water location was selected because it represents a narrow continental shelf environment and an adequate number of observations are available for analysis. The location is mid latitude and is under direct influence of the open ocean environment offshore. The one-degree square site selected for analysis is located on the La Perouse Bank outside of the strait. Data were screened to select only deep profiles covering 80 percent or more of the water column and were processed for four three-month seasons: winter (January–March), spring (April–June), summer (July–September) and fall (October–December). Each season will be briefly described. Figures containing statistical summaries, gradient statistics, composite plots and T–S diagrams are ordered by season at the end of the discussion.

Winter – The predominant sound speed profile gradient is positive from the surface to the bottom of the profile. Almost 98 percent of all profiles are classed as positive in the gradient summary table. In a few instances the positive gradient is modified by a negative gradient tail near the bottom. This is indicated in the increased percentage occurrence of negative gradients from the surface to depths below 100 m in the sound speed statistical summary. A narrow bottom channel exceeding 180 m depth crosses the shelf in the southeast part of the one-degree square. Several of the deep negative gradient tails appear in or near the channel. Because of the high percentage of positive gradient profiles during the winter, it is possible to select a typical positive gradient profile to represent this season for acoustic modeling. The T–S diagram indicates a moderately large salinity range created by dilution of the surface layer by rain and runoff. A single near-shore profile with a very low surface salinity is evident on the diagram.

Spring – A large percentage of non-positive gradient profiles is produced by the spring warming. Most of the positive gradient profiles were observed during early to mid April before the advent of strong surface heating. The T-S diagram for spring indicates that the high variability in surface sound speed is primarily temperature controlled with some salinity contribution in a few instances where surface dilution is evident. The variability realistically precludes the selection of a single typical profile to represent the entire transition season. Increased stability of the water column produced by the large temperature and salinity ranges is indicated by the sigma-T (density) range on the T-S diagram. About 34 percent of the profiles are classified as positive gradient with the remainder indicating a large variability in the strength of the negative gradients. Because spring is a season of transition, it is likely there would be better resolution of profile types in the monthly analysis.

Summer – The summer season exhibits 100 percent non-positive sound speed gradients. High surface sound speeds and very strong upper layer gradients characterize the profile set. The few profiles with shallow surface ducts are products of local wind mixing or eddies. A weak minimum is observed in the 50 m to 100 m depth range in many of the profiles. The T–S diagram indicates the overall variability is strongly temperature dependent. The profiles with surface temperatures above 12°C have the highest surface sound speeds. Also indicated is an example of salinity dilution produced near shore by local river runoff. A single non-positive profile with a strong thermocline can be used to represent the summer season at this location for modeling purposes.

Fall – Surface layer cooling reduces the strength of the negative gradient in the upper layer during the fall. About 75 percent of the observations indicate a positive gradient in the upper layer. A majority of the profiles classified as non-positive were observed during October or early November. Most of these profiles have a surface duct indicating the advent of seasonal mixing and layer deepening which characterizes this transition season. A weak sound speed minimum near 50–75 m is observed sometimes for profiles at locations where the shelf depth exceeds 100 m. The T-S diagram indicates the complexity and weakening of vertical stability in some of the profiles, in comparison to the summer profiles. Both gradient statistical tables indicate that the large percentage of positive profiles is produced by positive gradients in the upper 50 m. Overall gradients from the surface to depths below 50 m are primarily negative. It would be difficult to represent the entire fall season with a single profile.


126°
125°
124°
123°
VANCOUVER
ISLAND
La Perouse
Bank
19
Swiftsure
Bank
100
200
Barkley Canyon
Nitinat
Canyon
Umatilla
Reef
Race Rocks
1200
400
Juan de Fuca
Canyon
800
Deep
1300
Fan
Quinault Canyon
Sealion Rock
Grays Canyon
100
1200
1000
Guide Canyon
Willapa Seachannel
Willapa
Canyon
Astoria Canyon
800

ST. JUAN DE FUCA - WINTERS

*** STATISTICAL SUMMARY ***

DEPTH (M)		TEMPERATURE (C) MAX	MEAN	MIN	ST DEV		SALINITY (PPT) MAX	MEAN	MIN	ST DEV		SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM	
0	*	10.79	8.02	5.30	1.1092	*	32.51	31.36	26.37	1.0602	*	1486.0	1478.12	1467.0	4.2851	41	*
10	*	10.20	8.07	5.30	1.0156	*	32.52	31.68	29.85	.5184	*	1488.0	1478.90	1467.6	4.1368	41	*
20	*	10.20	8.18	6.55	.8979	*	32.53	31.92	31.00	.3461	*	1488.2	1479.82	1473.3	3.5499	41	*
30	*	10.21	8.24	6.70	.8757	*	32.55	32.07	31.18	.3280	*	1488.5	1480.79	1474.4	3.4691	41	*
50	*	10.19	8.30	6.96	.8196	*	32.80	32.34	31.60	.3410	*	1488.8	1481.71	1475.8	3.2372	41	*
75	*	10.15	8.31	7.35	.6991	*	33.42	32.81	32.28	.3192	*	1489.1	1482.78	1479.0	2.5977	32	*
100	*	10.11	8.26	7.28	.6771	*	33.76	33.20	32.40	.3660	*	1489.5	1483.06	1480.0	2.3435	26	*
125	*	9.91	8.31	7.20	.6986	*	33.83	33.35	32.50	.4272	*	1489.3	1483.83	1480.0	2.3209	19	*
150	*	9.07	8.26	7.20	.5199	*	33.80	33.67	32.95	.2824	*	1486.7	1484.71	1480.6	1.7532	9	*
200	*	8.50	8.06	7.62	.6223	*	33.90	33.90	33.90	.0000	*	1486.2	1484.55	1482.9	2.3335	2	*

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

ST. JUAN DE FUCA - WINTER

TOTAL NO. OF OBS: 41
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 33
MAX: 183 MEAN: 108.8 MIN: 53

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	9	94.3	85.7	80.6
75	5	94.9	86.7	82.4
100	6	100.0	88.4	83.3
125	10	97.7	87.9	80.6
150	3	96.8	87.4	82.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	38	92.7	.360	.099	.010	.0897	3	7.3	.200	.092	.015	.0965	0	.0
30	38	92.7	.267	.086	.007	.0669	2	4.9	.110	.077	.043	.0471	1	2.4
50	39	95.1	.212	.070	.012	.0503	2	4.9	.086	.057	.028	.0410	0	.0
75	28	87.5	.163	.059	.001	.0387	3	9.4	.035	.015	.001	.0174	1	3.1
100	24	92.3	.131	.045	.006	.0305	2	7.7	.016	.016	.015	.0007	0	.0
125	17	89.5	.065	.035	.007	.0223	2	10.5	.014	.010	.006	.0062	0	.0
150	7	77.8	.060	.031	.013	.0170	2	22.2	.007	.006	.005	.0014	0	.0
200	2	100.0	.040	.023	.005	.0247	0	.0	.000	.000	.000	.0000	0	.0

@XQT GRAD.ABS

40															
569	33	37	56	60	62	77	80	83	3	5	7	8	11	13	19
29	31	36	39	157	316	350	351	370	426	427	594	595	598	607	725
727	728	729	750	791	792	828	831								
1															
830															

SHALLOW WATER PROFILE GRADIENT SUMMARY

ST. JUAN DE FUCA - WINTER
TOTAL OBS 41

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

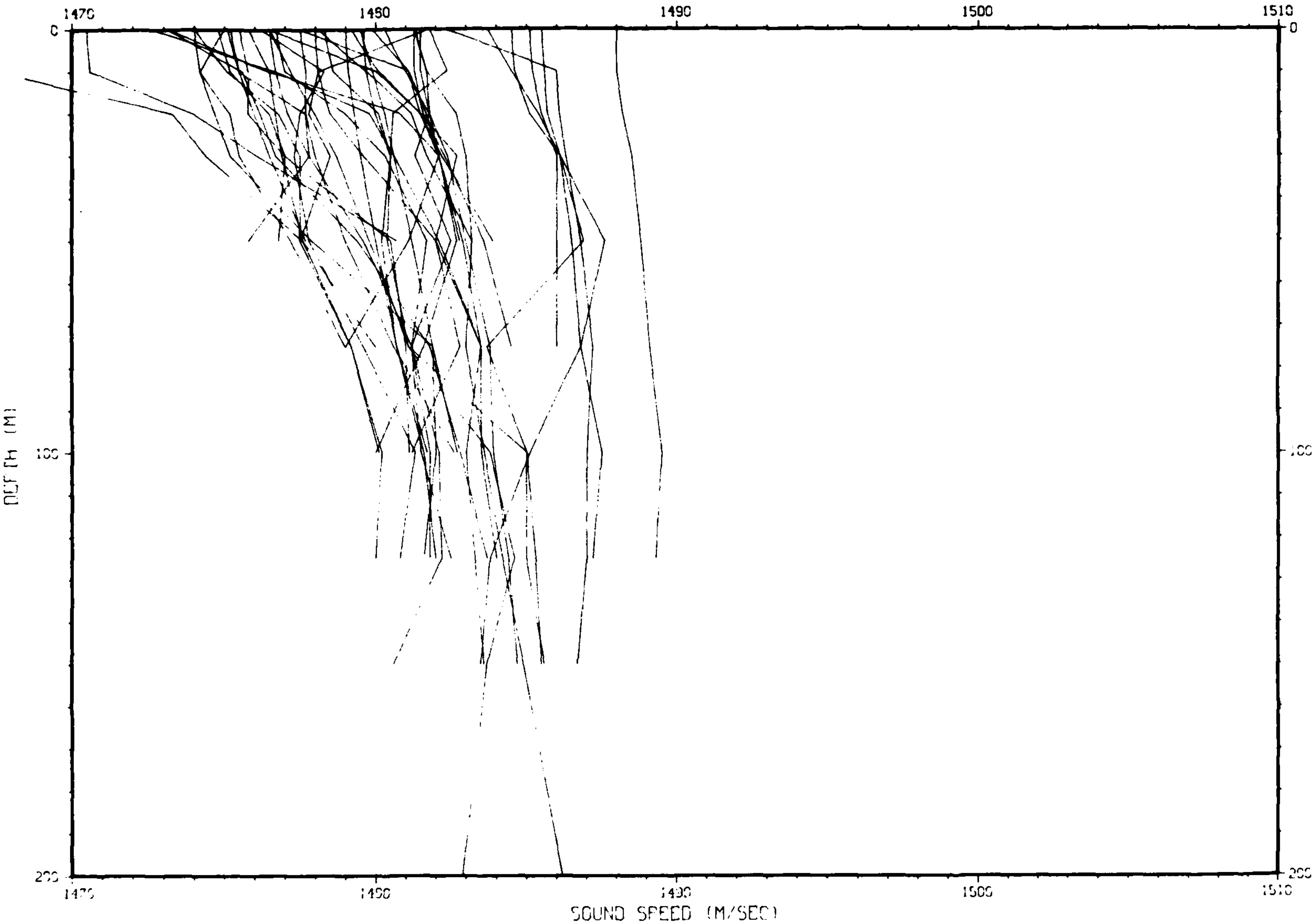
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	0										
30	4	9.8	9.8	.073	.112	.210	.066	1476.0	1479.3	57.3	4.
50	10	24.4	34.1	.024	.072	.204	.055	1478.9	1482.5	89.9	49.
75	7	17.1	51.2	.012	.070	.145	.042	1478.1	1483.3	104.7	37.
100	9	22.0	73.2	.015	.052	.131	.038	1478.1	1483.2	127.2	19.
125	6	14.6	87.8	.019	.051	.085	.022	1477.4	1483.1	146.0	10.
150	3	7.3	95.1	.029	.040	.060	.018	1478.7	1484.6	.0	0.
200	1	2.4	97.6	.040	.040	.040	.000	1478.1	1486.2	.0	0.
TOTAL	40										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

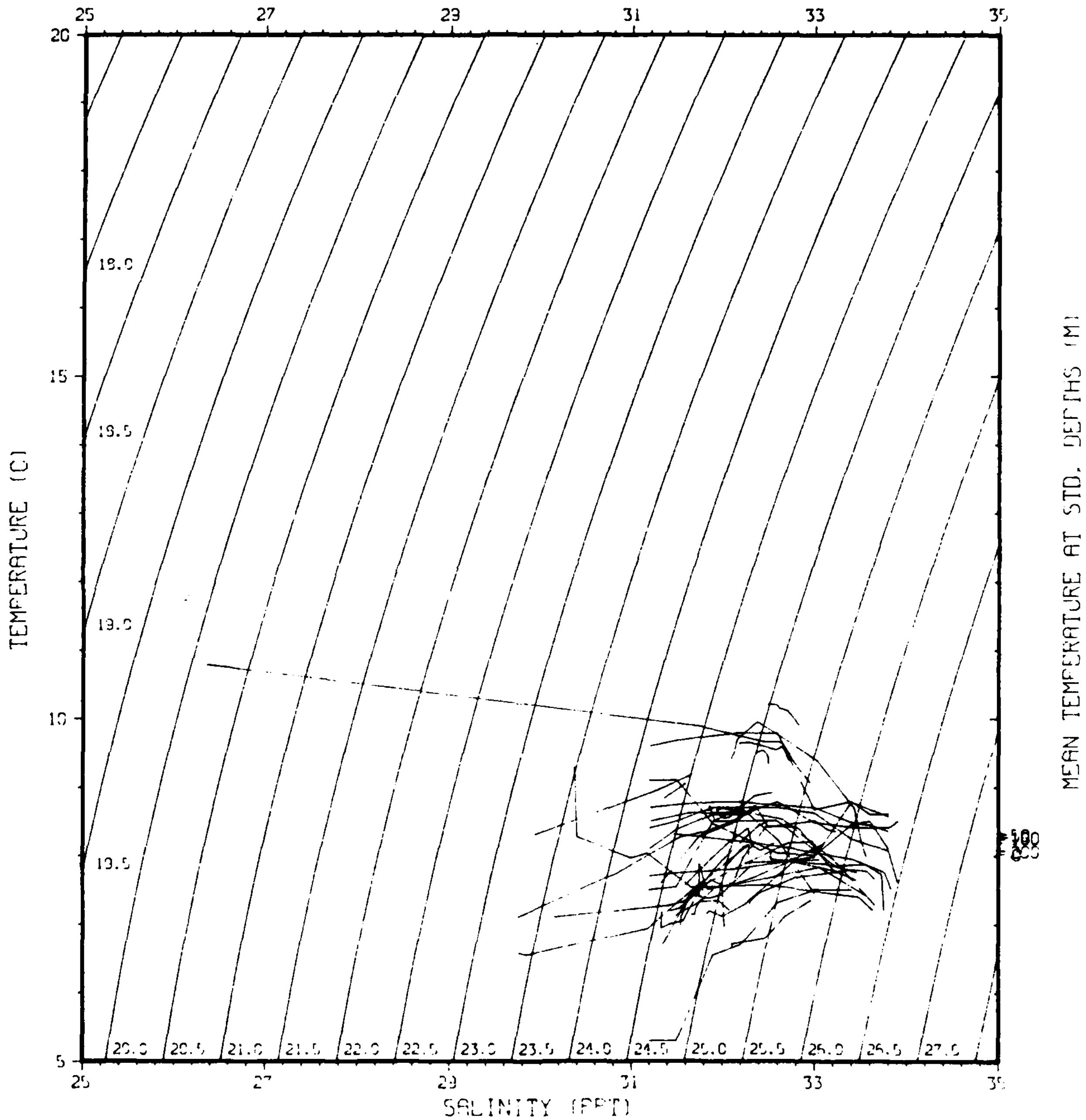
DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	MEAN	MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	MEAN	MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	0																
50	1	2.4	2.4	.086	.086	.086	.000	1	2.4	2.4	.054	.054	.054	.000	1481.8	1477.5	128.0
TOTAL	1																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 0. .0 PCT OF THE NEG GRAD OBS.

ST. JUAN DE FUCA - WINTER



ST. JUAN DE FUCA - WINTER



ST. JUAN DE FUCA - SPRINGS

*** STATISTICAL SUMMARY ***

DEPTH	TEMPERATURE (C)				SALINITY (PPT)				SOUND SPEED (M/SEC)				
(M)	MAX	MEAN	MIN	ST DEV	MAX	MEAN	MIN	ST DEV	MAX	MEAN	MIN	ST DEV	NUM
0	15.59	13.88	7.90	2.1107	32.33	30.69	25.56	1.3749	1505.2	1487.82	1477.0	7.2874	44
10	13.47	10.15	8.20	1.4435	32.53	31.36	29.11	.7085	1492.8	1486.27	1478.6	5.2656	44
20	11.42	9.32	7.96	.9141	32.57	31.79	30.52	.4416	1491.7	1483.99	1478.7	3.4333	44
30	10.44	8.68	7.66	.7457	32.67	32.09	31.13	.3622	1488.3	1482.88	1478.2	2.7850	44
50	9.59	8.34	7.07	.6391	33.29	32.44	31.48	.3588	1486.6	1481.64	1476.7	2.2949	44
75	9.37	8.01	6.61	.6762	33.56	32.85	31.75	.3895	1486.2	1481.31	1475.8	2.3315	44
100	8.78	7.68	6.42	.7172	33.82	33.38	32.48	.3178	1485.5	1481.13	1476.6	2.5999	36
125	8.69	7.45	6.14	.6536	33.87	33.56	32.57	.3332	1484.6	1480.85	1476.2	2.3615	24
150	8.80	7.33	6.13	.7664	33.86	33.79	33.54	.0942	1486.4	1480.96	1476.5	2.9171	10
200	7.18	7.13	7.09	.0636	33.90	33.90	33.90	.0000	1481.2	1481.00	1480.8	.2828	2

SHALLOW WATER PROFILE GRADIENT SUMMARY

NORTH SEA - SUMMER
TOTAL OBS 173

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	24	13.9	13.9	.000	.019	.070	.017	1502.2	1502.6	90.4	13.
30	16	9.2	23.1	.007	.030	.180	.044	1500.5	1501.4	94.9	15.
50	2	1.2	24.3	.010	.011	.012	.001	1495.2	1495.8	.0	0.
TOTAL	42										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	1	.6	.6	.973	.973	.973	.000	1	.6	.6	.020	.020	.020	.000	1501.8	1472.6	79.0
50	22	12.7	13.3	.330	.495	.640	.078	15	8.7	9.2	.004	.013	.032	.007	1504.1	1479.3	78.9
75	82	47.4	60.7	.109	.284	.437	.066	8	4.6	13.9	.004	.014	.060	.019	1503.2	1481.9	90.0
100	25	14.5	75.1	.095	.212	.299	.052	1	.6	14.5	.016	.016	.016	.000	1502.8	1481.6	114.0
125	1	.6	75.7	.202	.202	.202	.000								1501.0	1475.8	-1.0
TOTAL	131																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 106, 80.9 PCT OF THE NEG GRAD OBS.

SHALLOW WATER PROFILE GRADIENT SUMMARY

ST. JUAN DE FUCA - SPRING
TOTAL OBS 44

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

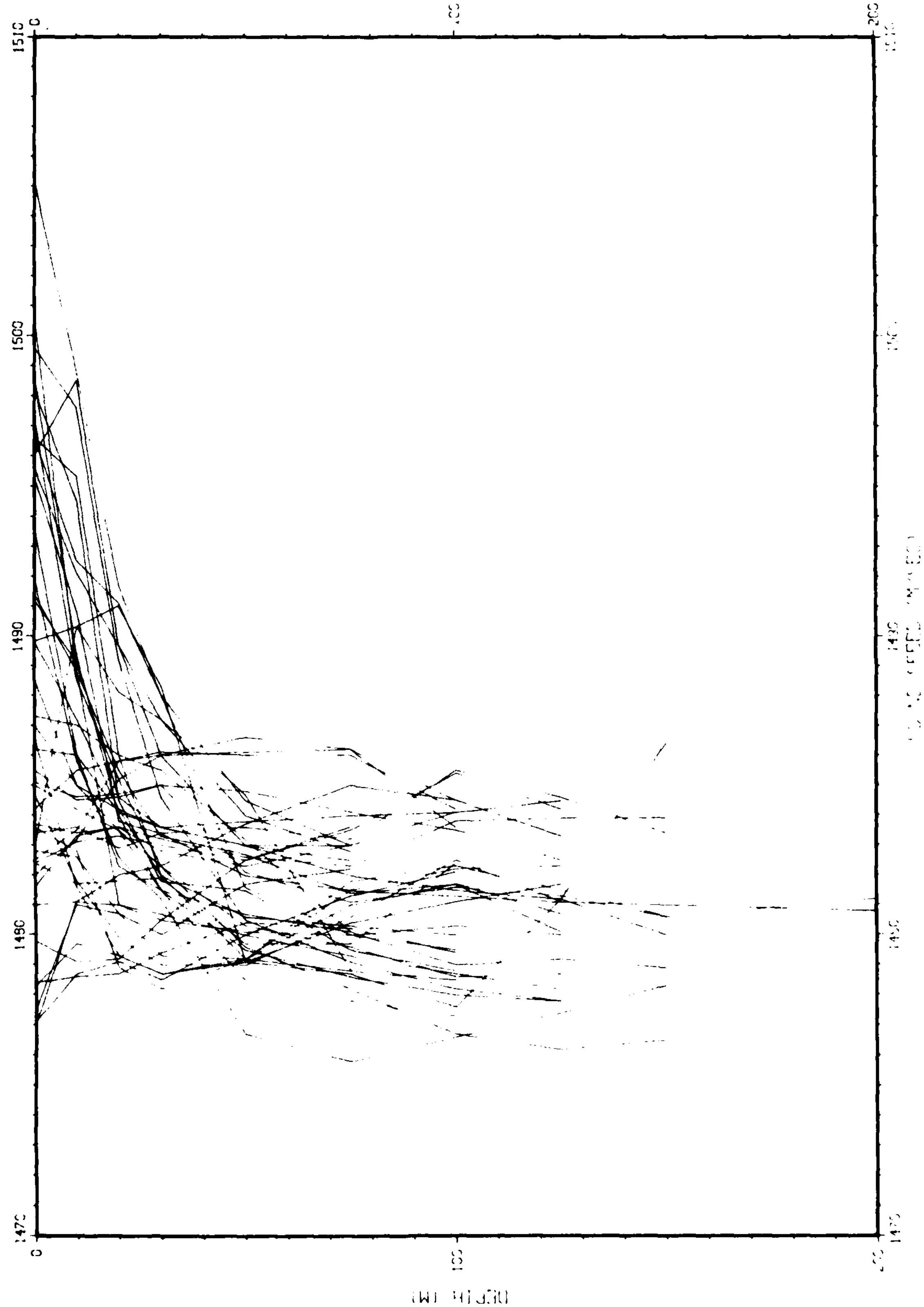
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	1	2.3	2.3	.060	.060	.060	.000	1489.8	1491.0	.0	0.
30	1	2.3	4.5	.120	.120	.120	.000	1482.5	1486.1	113.0	0.
50	2	4.5	9.1	.040	.044	.048	.006	1481.3	1483.5	108.5	12.
75	4	9.1	18.2	.056	.074	.107	.023	1479.1	1484.2	107.7	20.
100	5	11.4	29.5	.030	.041	.054	.011	1481.6	1483.9	131.2	30.
125	1	2.3	31.8	.027	.027	.027	.000	1478.3	1481.7	155.0	0.
150	1	2.3	34.1	.015	.015	.015	.000	1481.6	1483.9	155.0	0.
TOTAL	15										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

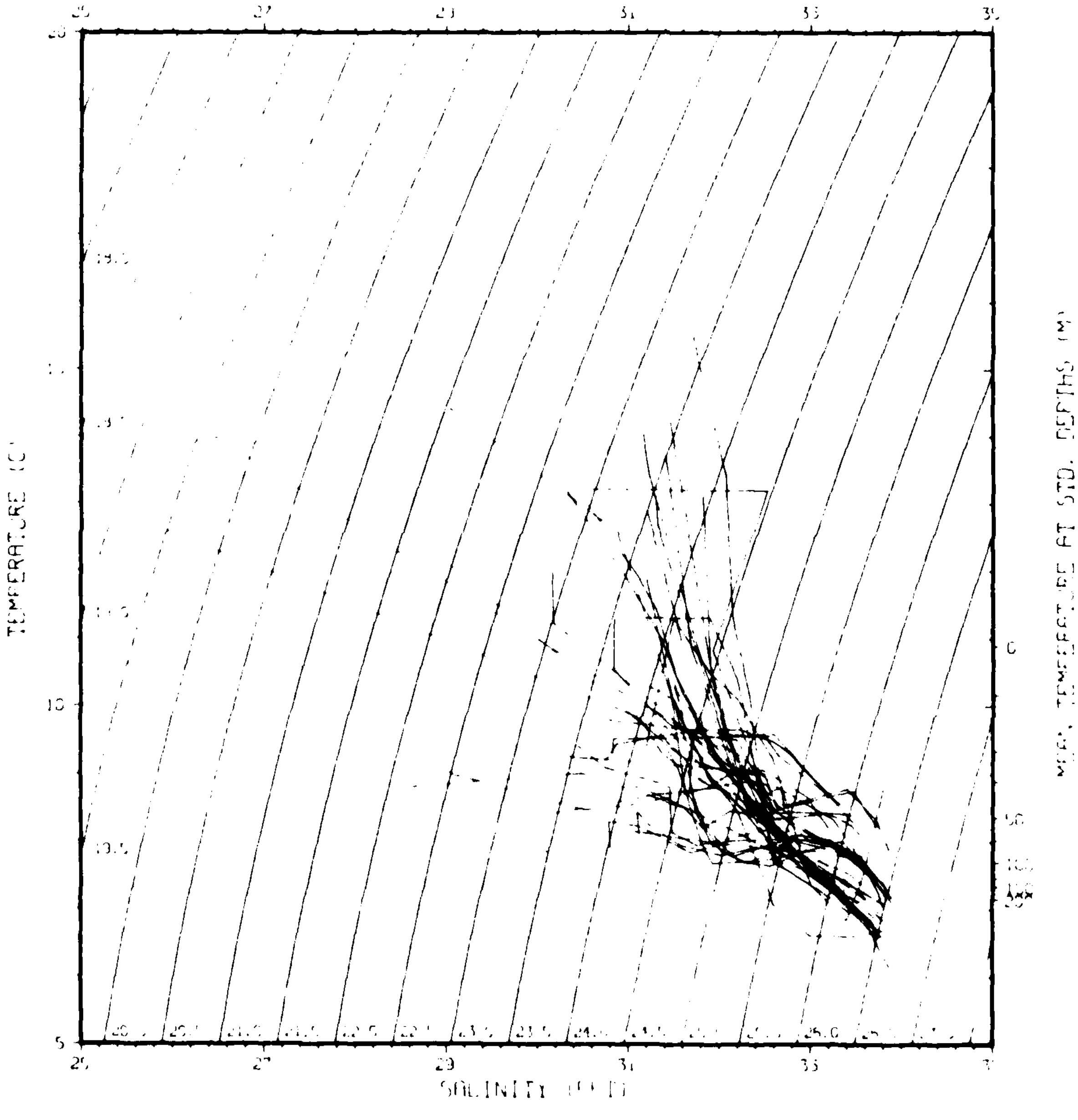
DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	3	6.8	6.8	.167	.202	.267	.054	3	6.8	6.8	.009	.032	.043	.019	1486.2	1480.2	150.0
50	2	4.5	11.4	.072	.093	.114	.030	2	4.5	11.4	.062	.066	.070	.006	1483.7	1479.1	157.5
75	7	15.9	27.3	.055	.139	.215	.055	1	2.3	13.6	.037	.033	.033	.000	1491.3	1480.9	73.5
100	6	13.6	40.9	.015	.108	.194	.069	1	2.3	15.9	.004	.004	.004	.000	1489.6	1476.6	120.5
125	7	15.9	56.8	.024	.144	.202	.063	1	2.3	18.2	.012	.012	.012	.000	1496.9	1478.9	144.4
150	3	6.8	63.6	.030	.062	.107	.040	1	2.3	20.5	.012	.012	.012	.000	1489.1	1479.6	90.5
200	1	2.3	65.9	.072	.072	.072	.000								1495.3	1480.8	-1.0
TOTAL	29																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 20. 69.0 PCT OF THE NEG GRAD OBS.

ST. JUAN DE FUCA - SPRING



ST. JUAN DE FUCA - SPRING



ST. JUAN DE FUCA - SUMMERS

*** STATISTICAL SUMMARY ***

DEPTH	TEMPERATURE (C)					SALINITY (PPT)					SOUND SPEED (M/SEC)					
(M)	MAX	MEAN	MIN	ST DEV		MAX	MEAN	MIN	ST DEV		MAX	MEAN	MIN	ST DEV	NUM	
0 •	15.10	13.19	10.10	2.2003	•	32.78	31.04	21.56	2.1751	•	1505.4	1496.17	1485.9	6.2504	22	•
10 •	14.26	11.33	8.05	1.5381	•	32.72	31.52	26.00	1.3055	•	1500.5	1490.59	1479.6	5.2906	22	•
20 •	10.55	9.06	7.70	.7596	•	33.05	32.03	28.53	.8802	•	1489.5	1483.22	1477.7	3.0435	22	•
30 •	9.39	8.17	7.16	.5388	•	33.48	32.34	29.11	.8342	•	1485.0	1480.46	1477.0	2.0437	22	•
50 •	9.00	7.59	6.77	.5504	•	33.73	32.72	29.74	.7977	•	1484.0	1479.01	1476.1	1.9431	22	•
75 •	8.37	7.35	6.51	.5462	•	33.79	33.01	29.97	.8085	•	1482.6	1478.85	1476.3	1.8800	20	•
100 •	8.04	7.01	6.35	.5219	•	33.92	33.34	30.19	.8514	•	1482.1	1478.39	1475.8	1.7358	17	•
125 •	7.52	6.86	6.32	.4260	•	33.93	33.43	30.41	.9606	•	1480.9	1479.29	1476.4	1.3899	12	•
150 •	7.15	6.65	6.33	.3542	•	33.94	33.84	33.80	.0700	•	1480.1	1478.27	1476.9	1.3326	4	•

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

ST. JUAN DE FUCA - SUMMER

TOTAL NO. OF OBS: 22
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 17
MAX: 183 MEAN: 120.6 MIN: 60

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	2	83.3	82.0	80.6
75	1	80.6	80.6	80.6
100	4	91.7	87.3	84.0
125	5	96.9	88.2	81.7
150	1	82.0	82.0	82.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	*	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	*	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	*	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	*	0	.0	.000	.000	.000	.0000	*	22	100.0	1.315	.647	.125	.3117	*	0	.0
30	*	0	.0	.000	.000	.000	.0000	*	22	100.0	.893	.524	.200	.2053	*	0	.0
50	*	0	.0	.000	.000	.000	.0000	*	22	100.0	.558	.343	.176	.1215	*	0	.0
75	*	0	.0	.000	.000	.000	.0000	*	20	100.0	.348	.241	.119	.0779	*	0	.0
100	*	0	.0	.000	.000	.000	.0000	*	17	100.0	.279	.179	.084	.0425	*	0	.0
125	*	0	.0	.000	.000	.000	.0000	*	12	100.0	.216	.143	.066	.0536	*	0	.0
150	*	0	.0	.000	.000	.000	.0000	*	4	100.0	.147	.104	.053	.0439	*	0	.0
200	*	0	.0	.000	.000	.000	.0000	*	0	.0	.000	.000	.000	.0000	*	0	.0

#PRT GRAD.ARS
0
0
22
45 41 43 43 57 58 72 74 84 310 312 319 335 341 342 358
581 451 492 645 827 836

SHALLOW WATER PROFILE GRADIENT SUMMARY

ST. JUAN DE FUCA - SUMMER
TOTAL OBS 22

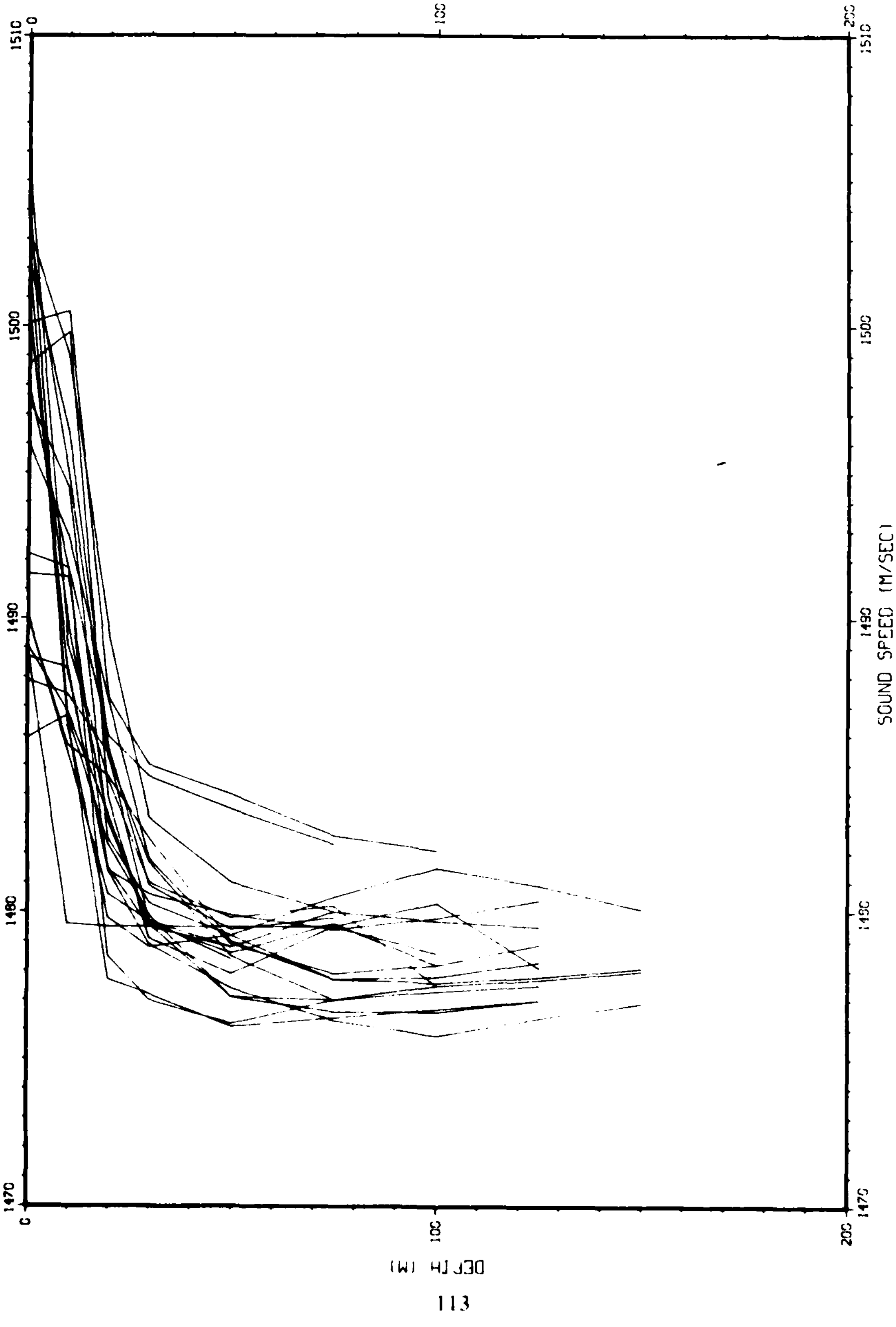
TOTAL 0

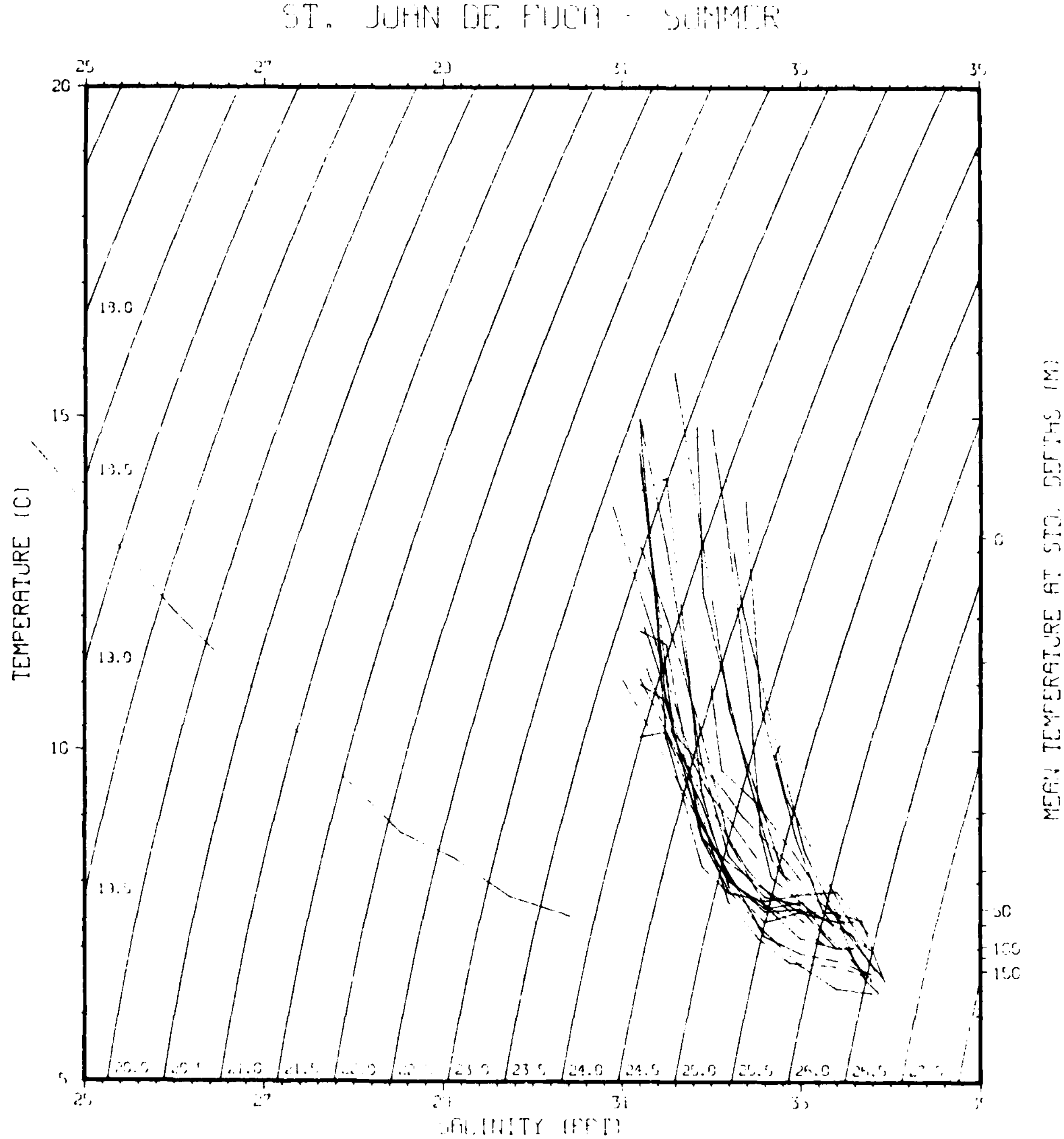
NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	MEAN	MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	MEAN	MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	1	4.5	4.5	.760	.760	.760	.000	1	4.5	4.5	.039	.039	.039	.000	1502.2	1476.6	.0
50	7	31.8	36.4	.190	.372	.558	.132	5	22.7	27.3	.012	.030	.048	.017	1496.5	1477.9	98.2
75	6	27.3	63.6	.119	.207	.348	.061	5	22.7	50.0	.010	.013	.020	.004	1494.1	1476.5	122.7
100	7	31.8	95.5	.105	.177	.279	.066	4	18.2	68.2	.010	.019	.028	.008	1495.7	1478.1	132.2
125	1	4.5	100.0	.190	.190	.190	.000								1503.2	1479.5	146.0
TOTAL	22																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 7, 31.8 PCT OF THE NEG GRAD OBS.

ST. JUAN DE FUCA - SUMMER





ST. JUAN DE FUCA - SUMMER
TEMPERATURE (C)
SALINITY (PPT)
MEAN TEMPERATURE AT STD. DEPTHS (M)

ST. JUAN DE FUCA - FALLS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	12.90	10.21	8.30	.9411	32.44	31.64	30.91	.4579	1495.3	1486.65	1478.8	3.3504	44
10	12.67	10.29	8.36	.9311	32.42	31.77	30.95	.3239	1495.7	1487.28	1479.6	3.3406	44
20	12.64	10.17	8.23	.9305	32.54	31.99	31.13	.2328	1495.6	1487.26	1479.8	2.9724	44
30	11.65	9.62	7.78	.9116	33.06	32.22	31.25	.2921	1492.7	1486.45	1475.6	3.2277	44
50	11.45	9.05	7.37	1.1486	33.75	32.58	31.42	.4532	1492.8	1484.37	1477.8	4.0182	44
75	10.55	7.93	7.03	.8193	33.77	33.16	32.66	.3181	1490.5	1481.21	1477.4	2.9089	29
100	9.44	7.53	6.86	.5972	33.86	33.50	33.24	.1845	1487.5	1480.51	1478.2	2.1165	27
125	8.69	7.44	6.72	.5625	33.87	33.64	33.60	.0857	1486.0	1480.69	1478.5	2.0469	18
150	8.20	7.38	6.88	.4375	33.94	33.81	33.60	.0733	1484.1	1481.02	1479.5	1.6382	13
200	7.34	7.16	7.04	.1567	33.90	33.90	33.90	.0000	1481.8	1481.10	1480.6	.6245	3

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

ST. JUAN DE FUCA - FALL

TOTAL NO. OF OBS: 44
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 26
MAX: 174 MEAN: 88.0 MIN: 56

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	15	89.3	83.7	80.6
75	1	86.2	86.2	86.2
100	6	96.2	87.1	84.7
125	3	88.7	85.8	80.6
150	1	86.2	86.2	86.2
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	34	77.3	.185	.076	.005	.0406	10	22.7	.350	.127	.005	.1105	0	.0
30	32	72.7	.143	.057	.010	.0338	12	27.3	.420	.176	.003	.1341	0	.0
50	20	45.5	.076	.045	.018	.0160	24	54.5	.338	.122	.020	.0865	0	.0
75	3	10.3	.036	.021	.005	.0154	26	89.7	.221	.087	.004	.0567	0	.0
100	0	.0	.000	.000	.000	.0000	27	100.0	.158	.065	.001	.0471	0	.0
125	1	5.6	.003	.003	.003	.0000	17	94.4	.113	.051	.002	.0386	0	.0
150	1	7.7	.002	.002	.002	.0000	12	92.3	.092	.045	.009	.0303	0	.0
200	0	.0	.000	.000	.000	.0000	3	100.0	.067	.041	.014	.0268	0	.0

@XQT GRAD.APS

33															
3	4	14	15	21	22	35	36	47	53	71	75	76	79	81	297
532	533	534	535	536	537	539	540	541	542	544	545	546	547	701	702
706															
11															
518	34	38	40	366	525	529	530	699	700	848					

SHALLOW WATER PROFILE GRADIENT SUMMARY

ST. JUAN DE FUCA - FALL
TOTAL OBS 44

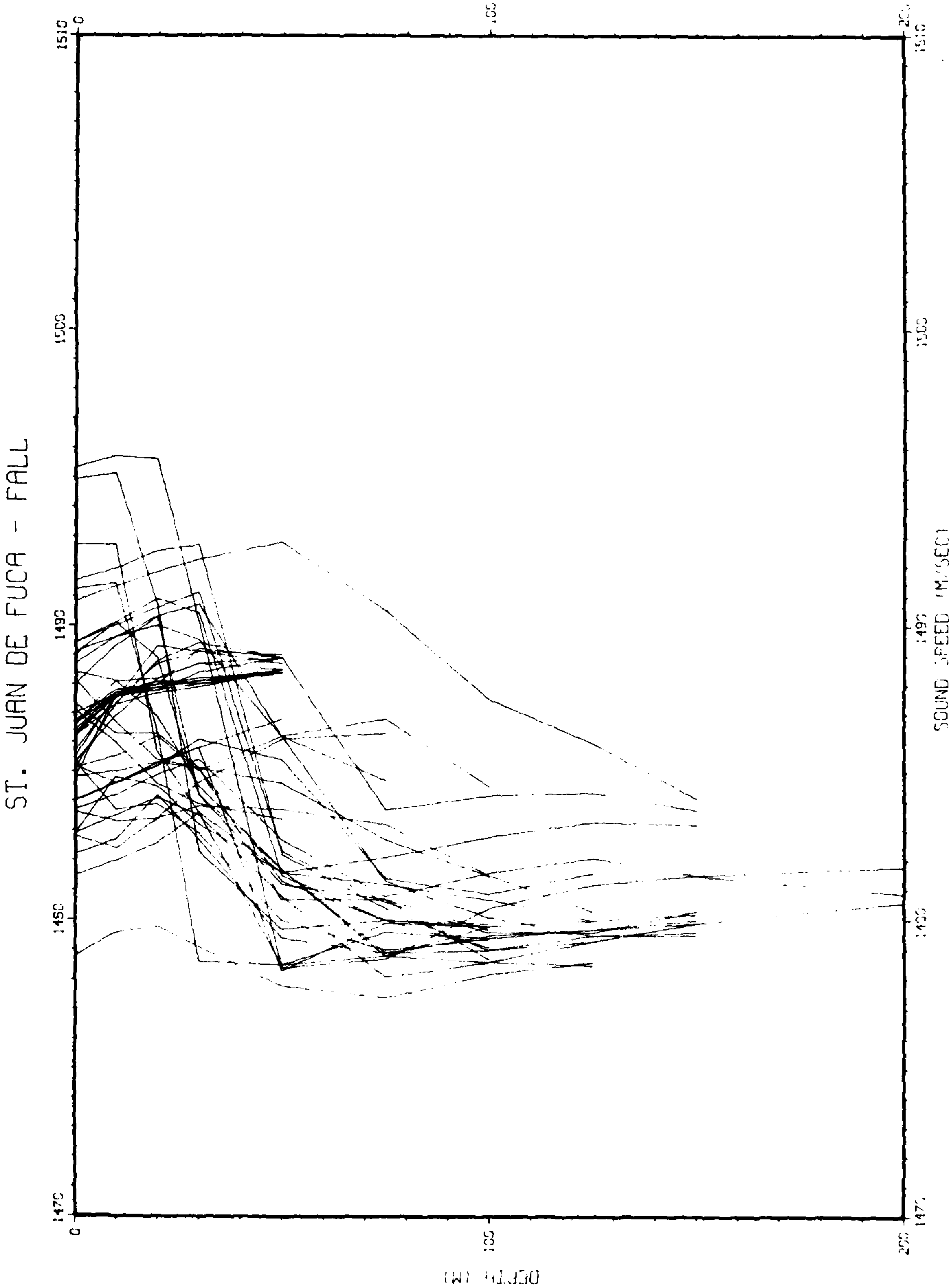
POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	8	18.2	18.2	.025	.071	.130	.032	1485.3	1486.7	117.0	56.
30	12	27.3	45.5	.040	.082	.143	.030	1485.6	1488.0	85.2	46.
50	11	25.0	70.5	.036	.047	.074	.012	1486.6	1488.8	59.2	3.
75	2	4.5	75.0	.040	.043	.046	.004	1484.4	1486.6	87.0	0.
TOTAL	33										

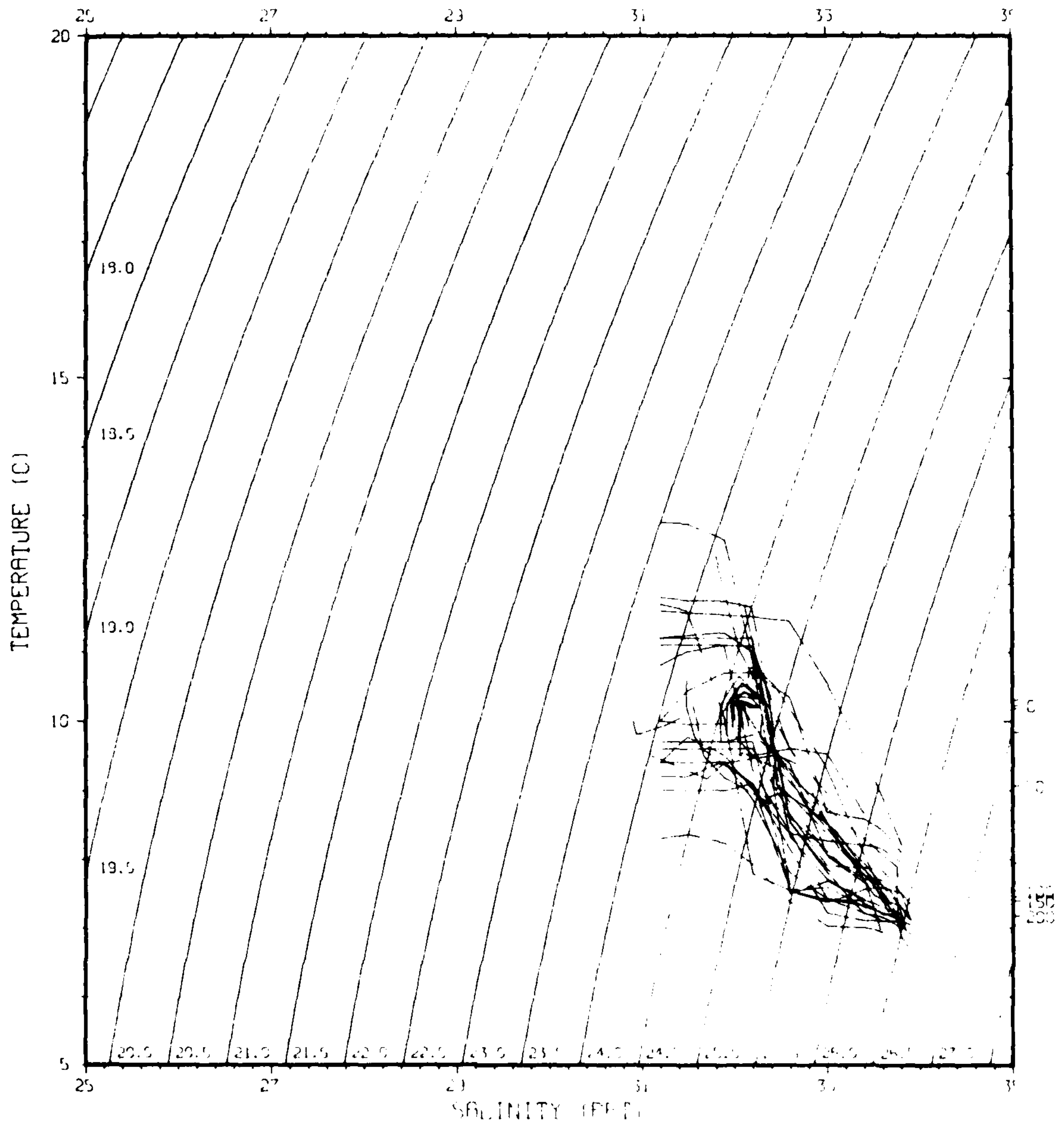
NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	GRADIENT TO SURFACE STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	GRADIENT BELOW MIN STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	0																
50	4	9.1	9.1	.026	.173	.338	.147	3	6.8	6.8	.015	.020	.023	.004	1489.1	1490.5	58.0
75	1	2.3	11.4	.084	.084	.084	.000	1	2.3	9.1	.016	.016	.016	.000	1485.3	1479.0	118.0
100	4	9.1	20.5	.066	.101	.158	.041								1489.8	1479.7	114.2
125	2	4.5	25.0	.079	.090	.102	.016								1490.5	1479.2	141.5
TOTAL	11																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 7, 63.6 PCT OF THE NEG GRAD OBS.


ST. JUAN DE FUCA - FALL
SOUND SPEED (M/SEC)
DEPTH (M)
1470
1480
1490
1500
1510
0
100
200

ST. JUAN DE FUCA - FALL



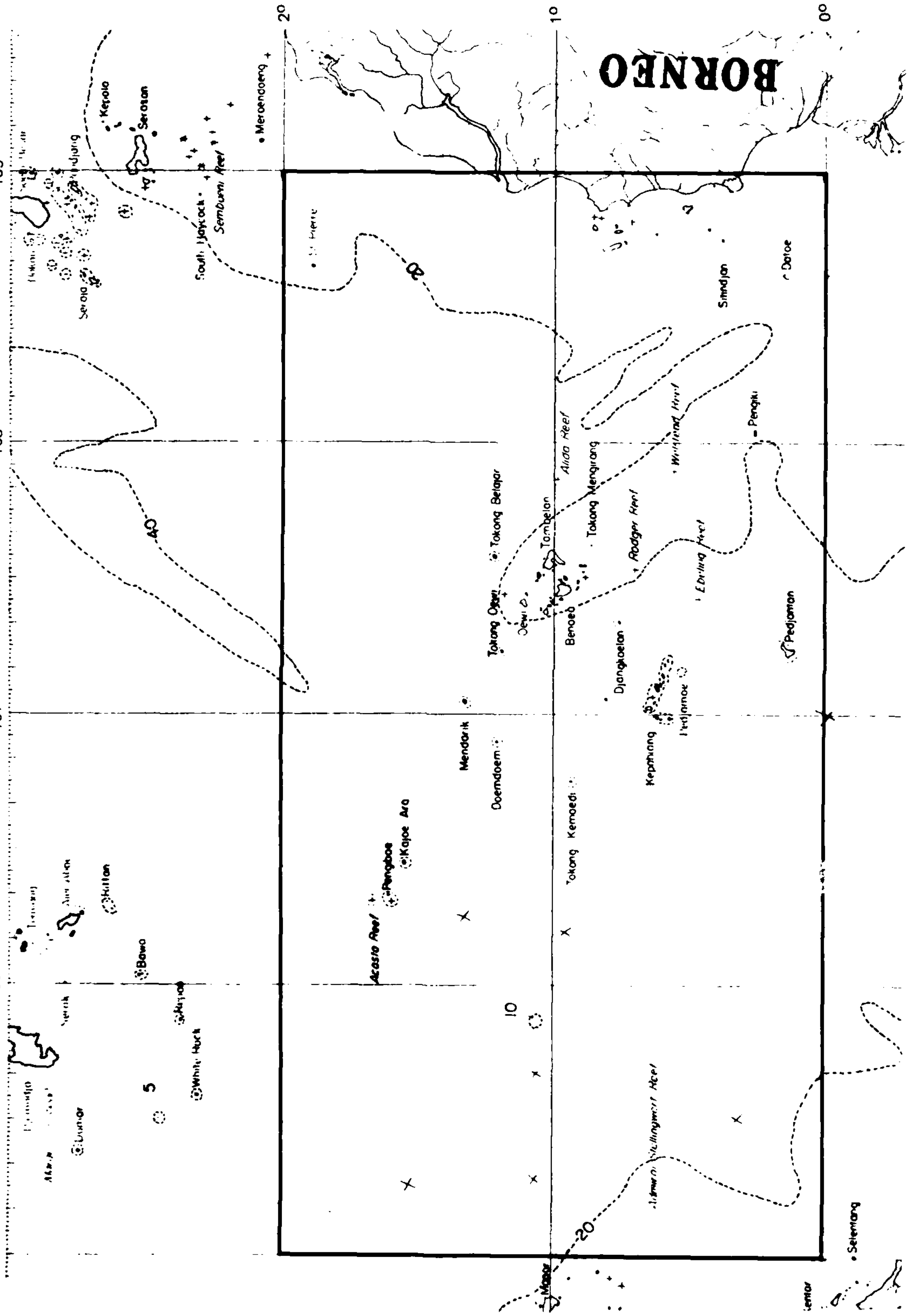
EAST OF SINGAPORE

This location was selected as an example of an equatorial shallow water environment. It also is isolated from open ocean influence. Six one-degree squares were processed to provide a reasonable number of observations. This area is very shallow with bottom depths ranging from about 25 m to 75 m. There were very few Nansen cast data in the set so shallow profiles were retained and the sample was supplemented with a large percentage of XBT data.

Strong seasonal variations would not be expected in the equatorial zone. However, some seasonal pattern was evident from atlas sea surface temperature charts, so two six-month seasons were selected based on this information. The northern hemisphere spring and summer months (April–September) were combined for summer and the standard fall and winter months (October–March) were processed as winter. Each season is briefly described and associated figures containing statistical tables, composite plots and T–S diagrams are located at the end of this section.

Winter – The shape of the winter profiles resembles winter data observed at much higher latitudes. The profiles are isothermal with weak positive sound speed gradients from the surface to the bottom of the profiles. About 82 percent of the observations are classified as positive gradient profiles. The one profile extending to 75 m has a strong negative gradient near the bottom, indicating a local cool bottom layer. The T–S diagram shows that a positive salinity gradient is relatively important in maintaining vertical stability at this location. The selection of a single positive gradient sound speed profile to represent the upper 50 m in this shallow water site for winter would seem to be supported. However, in water deeper than 50 m the presence of cooler deep water is suggested by the single deep observation, which, if present would create a gradient change near the bottom.

Summer – The strong seasonal signal in the upper layer temperatures and sound speeds observed in the other examples is not apparent for this equatorial location. The sound speed gradient in the upper 30 m primarily is positive, resulting in 60 percent of the profiles being classified as having a positive gradient. A thermocline below this depth is indicated on most of the profiles. Negative gradients with deep sound speed values less than winter sound speeds are observed. A few profiles extending below 30 m again indicate the presence of a cool bottom water while others do not. The data sample is inadequate to support firm conclusions about the causes of the observed sound speed structures. Both seasons indicate weak positive sound speed gradients in the upper 30 m. Below this depth, the winter is still primarily positive, but the summer is less certain.


BORNEO
2°
1°
0°
109°
108°
107°
106°
105°
Meroendoeng
Serasan
Kepala
Sembumi Reef
South Haycock
Simdjan
Datoe
Pengiki
Winifred Reef
Alida Reef
Tokong Mengirang
Rodger Reef
Ebeling Reef
Tokong Belajar
Tambelan
Tokong Ojan
Benoea
Djangkoelan
Pedjantan
Kepahiang
Mendarik
Doerndoem
Tokong Kemoedi
Kajoe Ara
Pengiboe
Acasta Reef
Hilton
Bawa
White Rock
Stellingwerf Reef
Seletiang
Serola
40
20
10
5

EAST OF SINGAPORE - WINTERS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	29.79	28.20	26.05	1.1398	33.60	32.68	30.99	.4521	1543.2	1539.31	1535.3	2.2352	40
10	29.60	28.11	26.00	1.1122	33.58	32.91	32.13	.2964	1542.6	1539.51	1535.3	2.2309	40
20	29.60	28.06	26.00	1.0961	33.55	33.03	32.16	.2563	1542.9	1539.69	1535.8	2.2019	40
30	29.40	27.95	25.98	1.0646	33.84	33.22	32.70	.2154	1543.8	1539.81	1535.9	2.2434	38
50	29.33	27.76	25.95	1.0386	33.86	33.37	32.75	.2357	1544.0	1539.90	1536.2	2.3235	22
75	26.27	26.27	26.27	.0000	33.69	33.69	33.69	.0000	1537.5	1537.50	1537.5	.0000	1

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

EAST OF SINGAPORE - WINTER

TOTAL NO. OF OBS: 40
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 17
MAX: 80 MEAN: 52.1 MIN: 33

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	2	46.5	46.0	45.5
30	5	90.9	75.0	57.7
50	9	98.0	87.9	76.9
75	1	93.8	93.8	93.8
100	0	.0	.0	.0
125	0	.0	.0	.0
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	32	80.0	.115	.032	.005	.0231	7	17.5	.090	.036	.005	.0331	1	2.5
30	30	78.9	.093	.029	.007	.0197	8	21.1	.057	.022	.003	.0189	0	.0
50	17	77.3	.060	.026	.006	.0155	4	18.2	.022	.012	.002	.0091	1	4.5
75	0	.0	.000	.000	.000	.0000	1	100.0	.076	.076	.076	.0000	0	.0
100	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
125	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

```
@XQT GRAD.ABS
  33
   3    4    5    9   11   14   16   18   19   23   24   26   27   28   30   33
  44   52   53    4   .6    7    9   11   12   13   14   16   17   18   20   27
  36
   7
  17   20   34   36   24   25   34
```

SHALLOW WATER PROFILE GRADIENT SUMMARY

EAST OF SINGAPORE - WINTER
TOTAL OBS 40

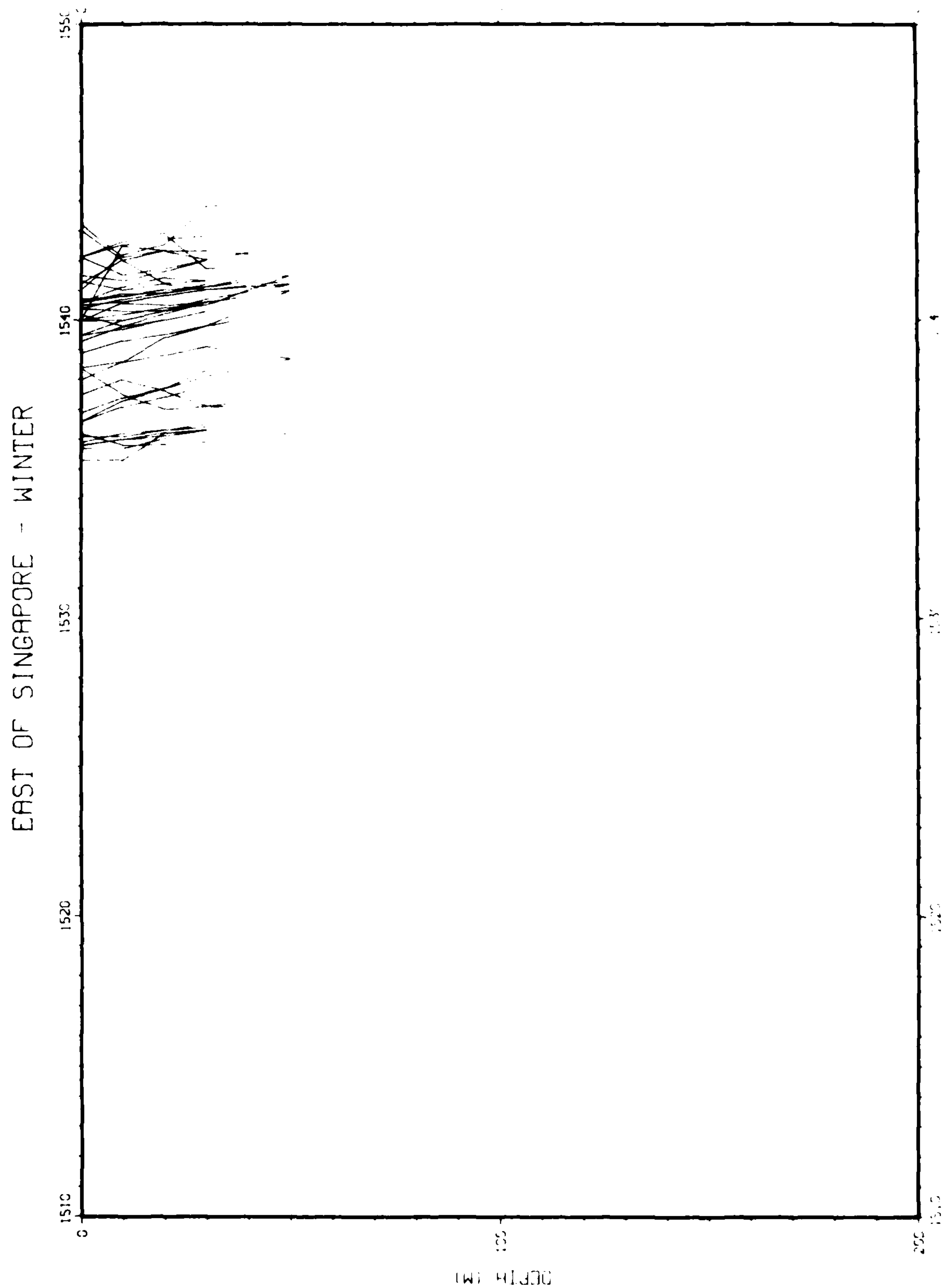
POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

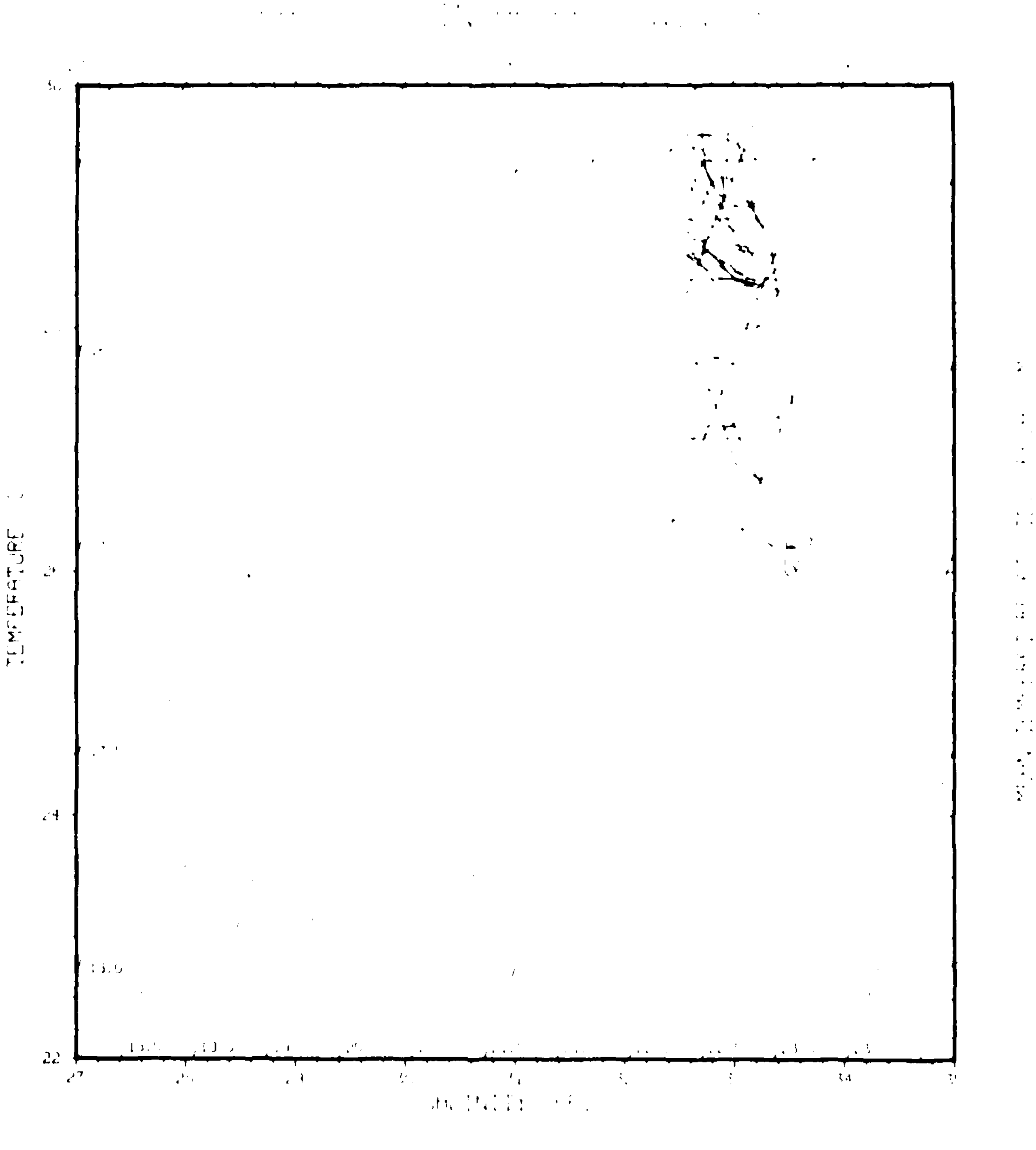
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	4	10.0	10.0	.015	.030	.040	.012	1540.7	1541.3	43.5	1.
30	12	30.0	40.0	.017	.030	.057	.012	1538.6	1539.5	43.7	8.
50	17	42.5	82.5	.010	.026	.060	.015	1538.6	1540.0	57.1	4.
TOTAL	33										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	1	2.5	2.5	.000	.000	.000	.000	1	2.5	2.5	.250	.250	.250	.000	1540.0	1540.0	41.0
10	1	2.5	5.0	.060	.060	.060	.000	1	2.5	5.0	.025	.025	.025	.000	1542.1	1541.5	.0
20	2	5.0	10.0	.070	.080	.090	.014	2	5.0	10.0	.010	.013	.017	.005	1540.7	1539.1	33.0
30	1	2.5	12.5	.010	.010	.010	.000								1541.3	1541.0	-1.0
50	1	2.5	15.0	.008	.008	.008	.000								1537.5	1537.1	-1.0
75	1	2.5	17.5	.076	.076	.076	.000								1543.2	1537.5	80.0
TOTAL	7																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 3, 42.9 PCT OF THE NEG GRAD OBS.


EAST OF SINGAPORE - WINTER
1510
1520
1530
1540
1550
0
100
200
DEPTH (M)


22
24
TEMPERATURE

EAST OF SINGAPORE - SUMMERS

*** STATISTICAL SUMMARY ***

DEPTH	TEMPERATURE (C)				SALINITY (PPT)				SOUND SPEED (M/SEC)				
(M)	MAX	MEAN	MIN	ST DEV	MAX	MEAN	MIN	ST DEV	MAX	MEAN	MIN	ST DEV	NUM
0	30.40	29.14	27.31	.6412	33.32	32.56	30.42	.4740	1543.6	1541.19	1537.9	1.4508	35
10	29.79	28.97	27.26	.5461	33.29	32.81	31.30	.3600	1543.0	1541.26	1537.9	1.1892	35
20	29.70	28.63	27.31	.5298	33.51	33.00	32.40	.2156	1543.1	1541.32	1538.2	1.1195	35
30	29.53	28.66	27.16	.6140	33.46	33.15	32.44	.2273	1543.1	1541.25	1538.1	1.2782	31
50	26.90	27.45	24.19	1.3542	33.94	33.44	33.06	.1564	1542.3	1539.70	1532.5	2.9756	18

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

EAST OF SINGAPORE - SUMMER

TOTAL NO. OF OBS: 35 — NO. OF OBS WITH RECORDED BOTTOM DEPTH: 10

PROFILES REJECTED (TOO DEEP): 0 — MAX: 64 MEAN: 50.0 MIN: 32

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	2	50.0	45.8	41.7
30	3	93.8	75.5	57.7
50	5	98.0	87.4	78.1
75	0	.0	.0	.0
100	0	.0	.0	.0
125	0	.0	.0	.0
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	20	57.1	.150	.039	.005	.0330	14	40.0	.130	.040	.005	.0356	1	2.9
30	21	67.7	.107	.032	.003	.0257	10	32.3	.123	.050	.007	.0396	0	.0
50	2	11.1	.034	.028	.022	.0085	16	88.9	.174	.052	.002	.0530	0	.0
75	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
100	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
125	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

```
BXQT GRAD.ABS
   21
    1    2    4   10   21   22   25   32   43   44   48   49   50   51    1    5
   10   19   23   26   32
   14
    8   12   13   15   37   39   41   42   45   54   55    2   30   31
```

SHALLOW WATER PROFILE GRADIENT SUMMARY

EAST OF SINGAPORE - SUMMER
TOTAL OBS 35

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

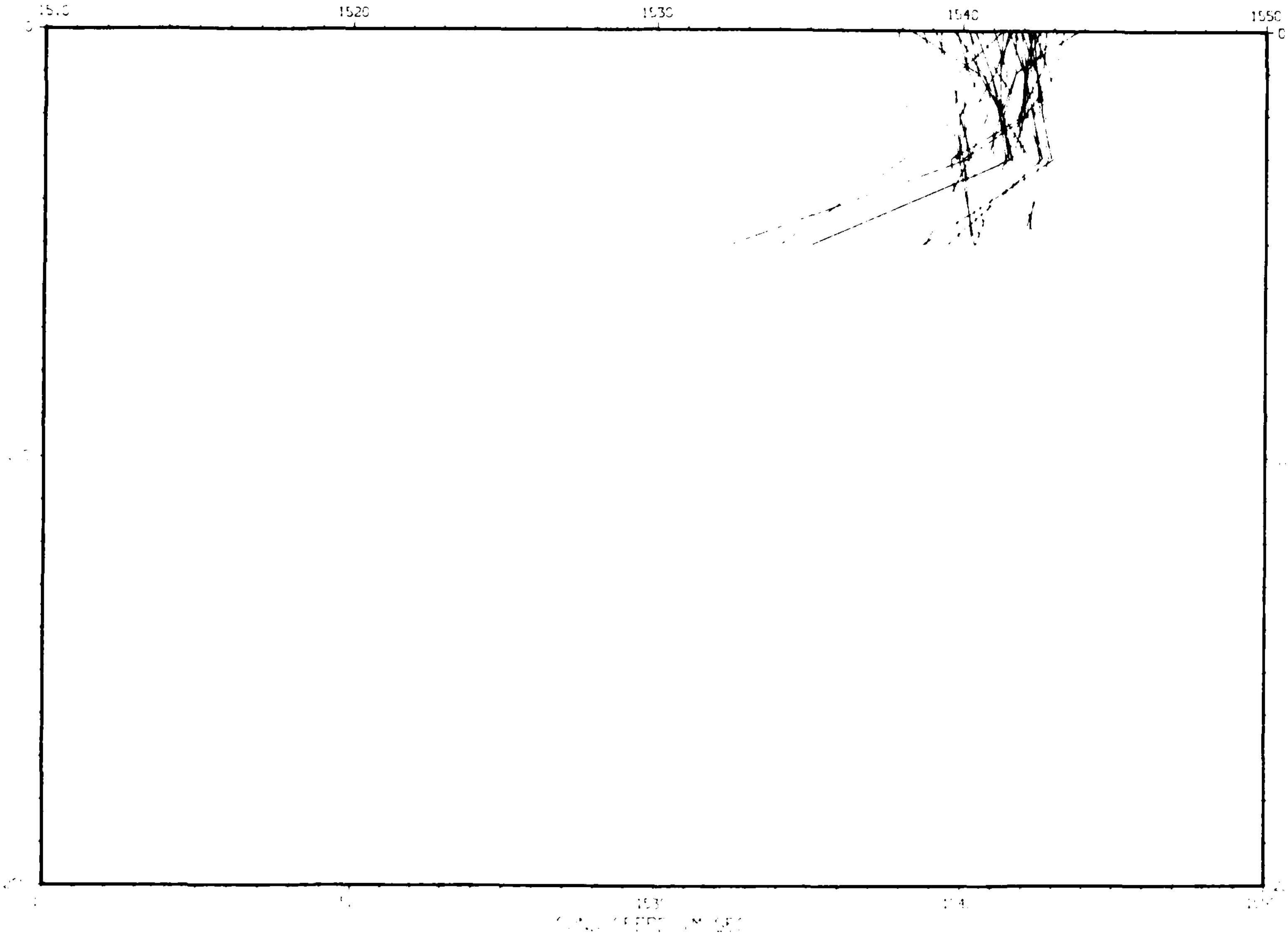
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	3	8.6	8.6	.015	.027	.050	.020	1539.8	1540.3	54.3	9.
30	16	45.7	54.3	.010	.038	.107	.025	1540.9	1542.0	48.0	14.
50	2	5.7	60.0	.022	.026	.034	.008	1539.2	1540.6	.0	0.
TOTAL	21										

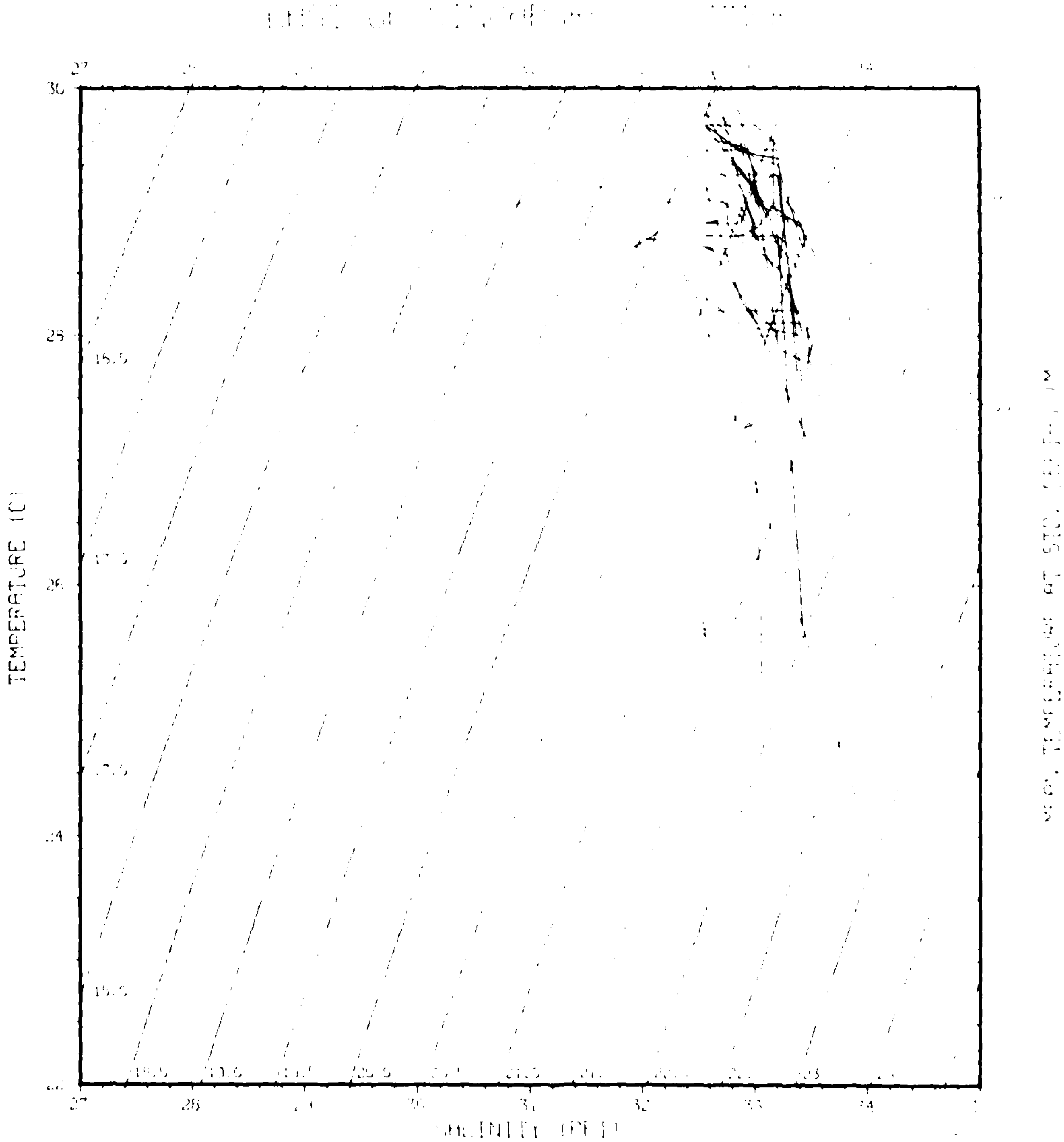
NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	MEAN	MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	MEAN	MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	6	17.1	17.1	.009	.028	.060	.028	3	8.6	8.6	.010	.019	.030	.010	1541.9	1541.4	12.7
30	6	17.1	34.3	.007	.056	.123	.049	3	8.6	17.1	.005	.012	.015	.006	1541.9	1540.3	25.7
50	2	5.7	40.0	.019	.096	.174	.110								1543.1	1538.2	-1.0
TOTAL	14																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 8, 57.1 PCT OF THE NEG GRAD OBS.

EAST OF SINGAPORE - SUMMER




TEMPERATURE (C)
30
28
26
24
27
28
31
32
33
34

LANDS END

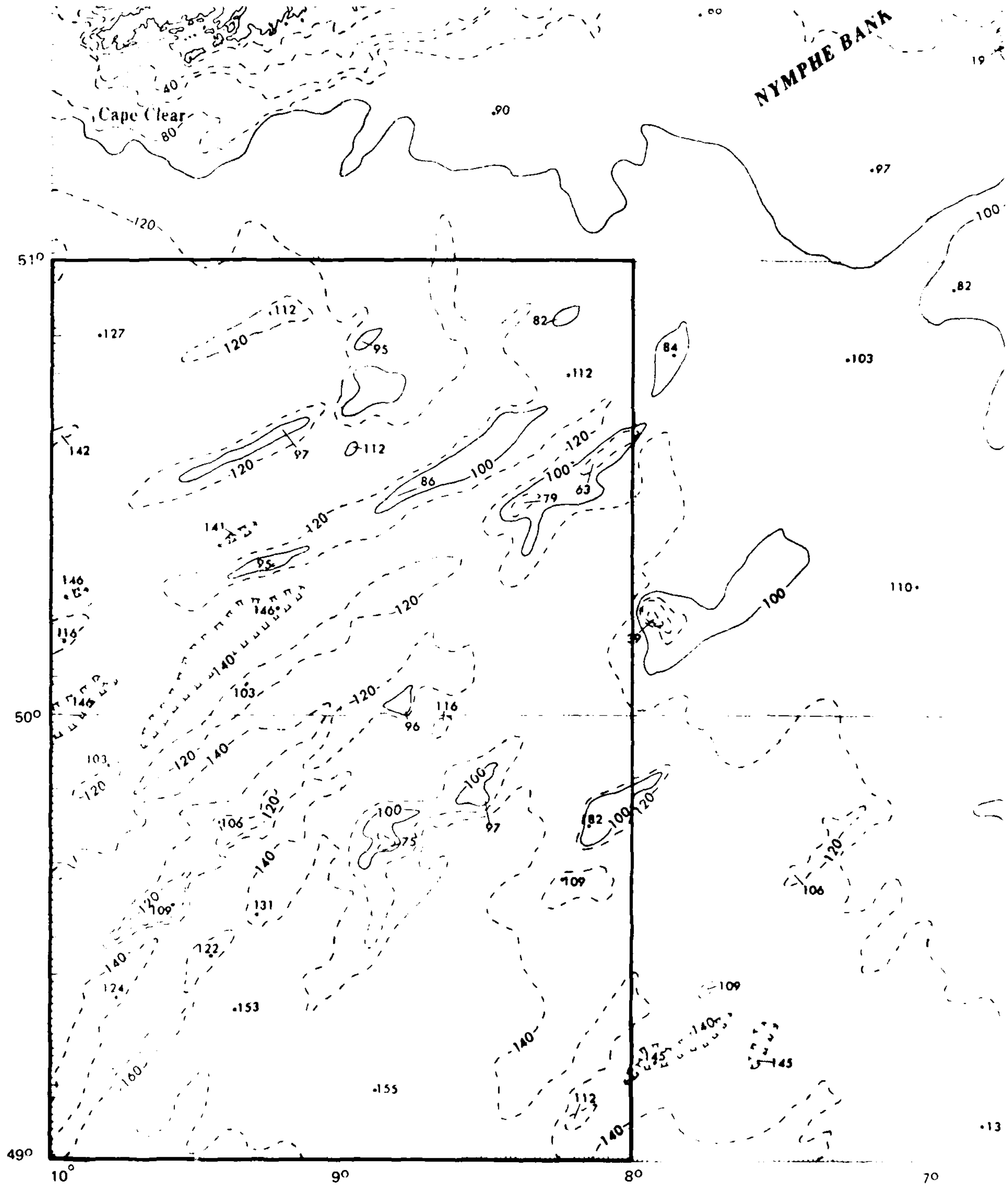
This location represents a high latitude continental shelf exposed to the influence of open ocean circulation of the North Atlantic current extension of the Gulf Stream. This can be contrasted to the relatively isolated North Sea location. For consistency, data were screened to select only deep profiles covering 80 percent or more of the water column and were processed for the same four three-month seasons used for the Strait of Juan de Fuca and the North Sea. Statistical summaries, composite profile plots and T–S diagrams are provided following the discussion.

Winter – The predominant winter sound speed profile shape is positive from the surface to the bottom, resembling the structure observed for winter in the other shallow water locations. The profile gradients are quite consistent with a mean of 0.017 (m/s)/m to 0.020 (m/s)/m. The vertical temperature distribution tends to be isothermal with a very weak positive salinity gradient indicated on the winter T–S diagram. Spatial variation, with higher sound speeds observed at lower latitudes, and year to year variations both contribute to the observed spread in absolute sound speeds within the profile set. All profiles are classified as positive gradient and a choice of a representative profile for acoustic modeling is not difficult.

Spring – Seasonal warming in the upper layers produces negative sound speed gradients and 80 percent of the profiles are classified as non-positive. This surface warming increases vertical stability (see the T–S diagram) and inhibits overturn and mixing. The deep sound speed structure tends to maintain the positive gradient of the winter, producing a sound speed minimum at 50 m to 75 m for many of the deeper profiles. Surface warming proceeds through this transition season and by June essentially all profiles are classed as non-positive gradients. The choice of a single non-positive gradient profile to represent this data set can be made, although the range of observed gradients is relatively high.

Summer – Upper layer sound speeds are higher than the spring, but several profiles have a greater surface layer depth resulting in a slight increase in the percentage of positive gradient profiles over the spring. This is opposite to the trend expected as a result of surface heating where the percentage of non-positive profiles would increase during the summer as observed in the North Sea. This may indicate the influence of strong circulation in the Lands End situation in contrast to the more isolated North Sea. A high gradient layer is observed below the surface layer and a sound speed minimum is produced in the 50 m to 75 m depth range. The high stability of the water column above the sound speed minimum is produced by the large temperature gradient indicated on the T–S diagram. Because the presence of a relatively deep surface duct results in a positive classification for 27 percent of the observed profiles, this must be considered when selecting a single profile to represent the summer season.

Fall – Seasonal cooling and overturn of the surface layer causes the fall surface duct to deepen considerably. This results in a positive classification for over 95 percent of the observations. Most of the deeper profiles, however, still have an overall negative sound speed gradient from surface to depths of 75 m and below. By mid November much of the thermocline is destroyed resulting in deep surface layers and only a weak negative gradient layer above the sound speed minimum near 75 m. Two profile types result from the progressive cooling of the upper layer as seen on the T–S diagram and the composite plot. The basic difference is in the depth of the surface duct and strength of the below-layer gradient.



Cape Clear
NYMPHE BANK
51°
50°
49°
10°
9°
8°
7°

LANDS END - WINTERS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	11.00	9.74	8.84	.5540	35.54	35.27	34.91	.1153	1493.6	1489.65	1486.5	1.8646	50
10	10.90	9.72	8.81	.5850	35.63	35.27	35.02	.1193	1493.7	1489.73	1486.2	1.9915	50
20	11.02	9.73	8.75	.6096	35.51	35.26	35.04	.1093	1494.0	1489.90	1486.1	2.0715	50
30	11.14	9.74	8.76	.6312	35.54	35.27	35.06	.1084	1494.7	1490.13	1486.3	2.1617	50
50	11.30	9.76	8.77	.6588	35.54	35.28	35.07	.1074	1495.5	1490.54	1486.7	2.2351	50
75	11.30	9.79	8.76	.6598	35.53	35.28	35.06	.1067	1496.0	1491.00	1487.1	2.2543	50
100	11.30	9.78	8.78	.6644	35.54	35.29	35.07	.1073	1496.4	1491.44	1487.6	2.2568	49
125	11.30	10.17	9.00	.6831	35.54	35.36	35.15	.0863	1496.9	1492.27	1489.1	2.2584	24
150	9.95	9.95	9.95	.0000	35.32	35.32	35.32	.0000	1492.4	1492.40	1492.4	.0000	1

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

LANDS END - WINTER

TOTAL NO. OF OBS: 50
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 41
MAX: 148 MEAN: 122.3 MIN: 90

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	0	.0	.0	.0
75	1	83.3	83.3	83.3
100	24	95.2	87.0	80.6
125	16	96.2	92.8	84.5
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

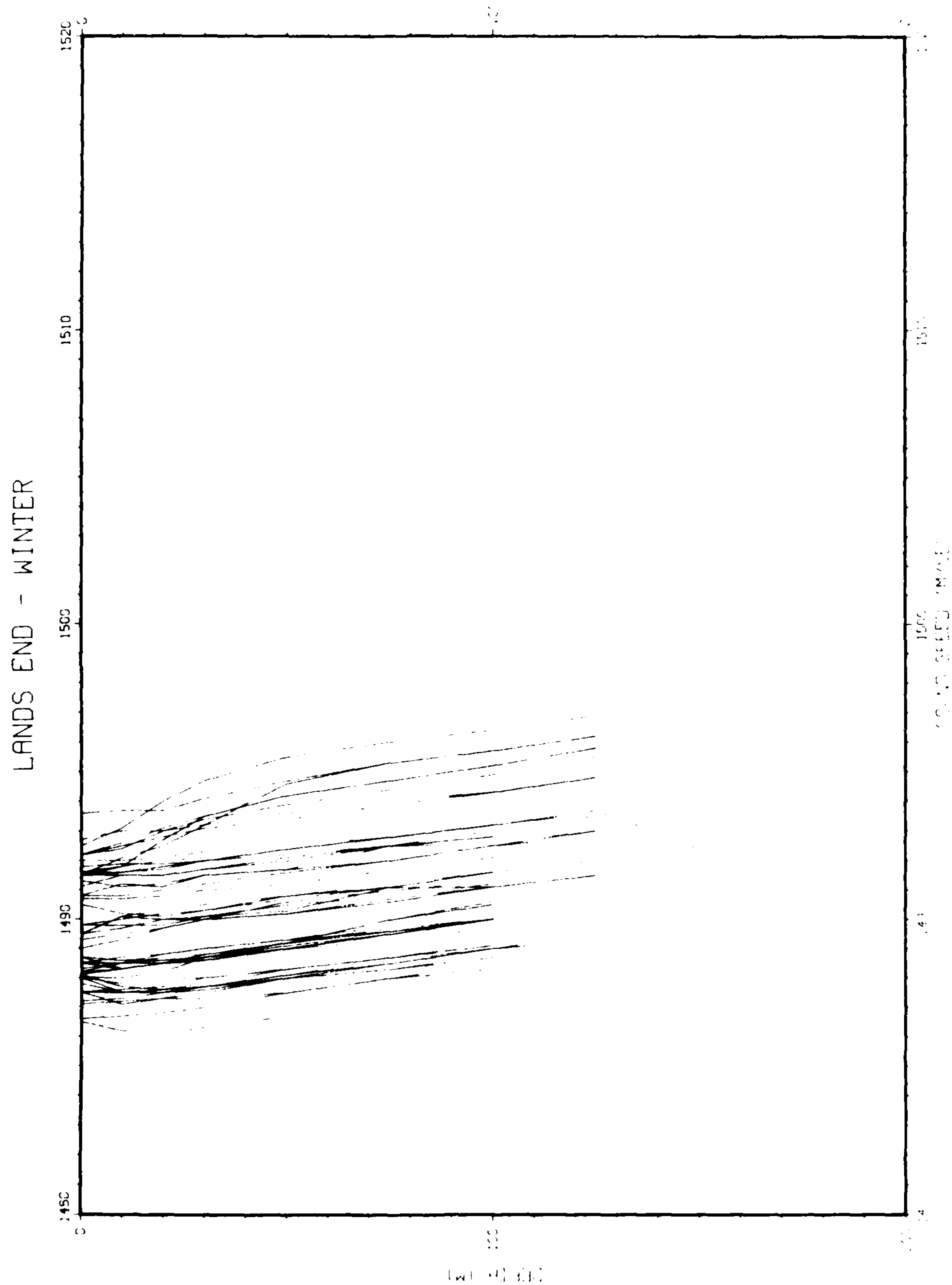
	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	34	68.0	.075	.022	.005	.0166	9	18.0	.025	.014	.005	.0081	7	14.0
30	41	82.0	.073	.021	.003	.0157	7	14.0	.010	.007	.003	.0027	2	4.0
50	49	98.0	.062	.018	.002	.0129	0	.0	.000	.000	.000	.0000	1	2.0
75	50	100.0	.051	.016	.007	.0090	0	.0	.000	.000	.000	.0000	0	.0
100	49	100.0	.042	.016	.010	.0069	0	.0	.000	.000	.000	.0000	0	.0
125	24	100.0	.038	.020	.012	.0075	0	.0	.000	.000	.000	.0000	0	.0
150	1	100.0	.006	.006	.006	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

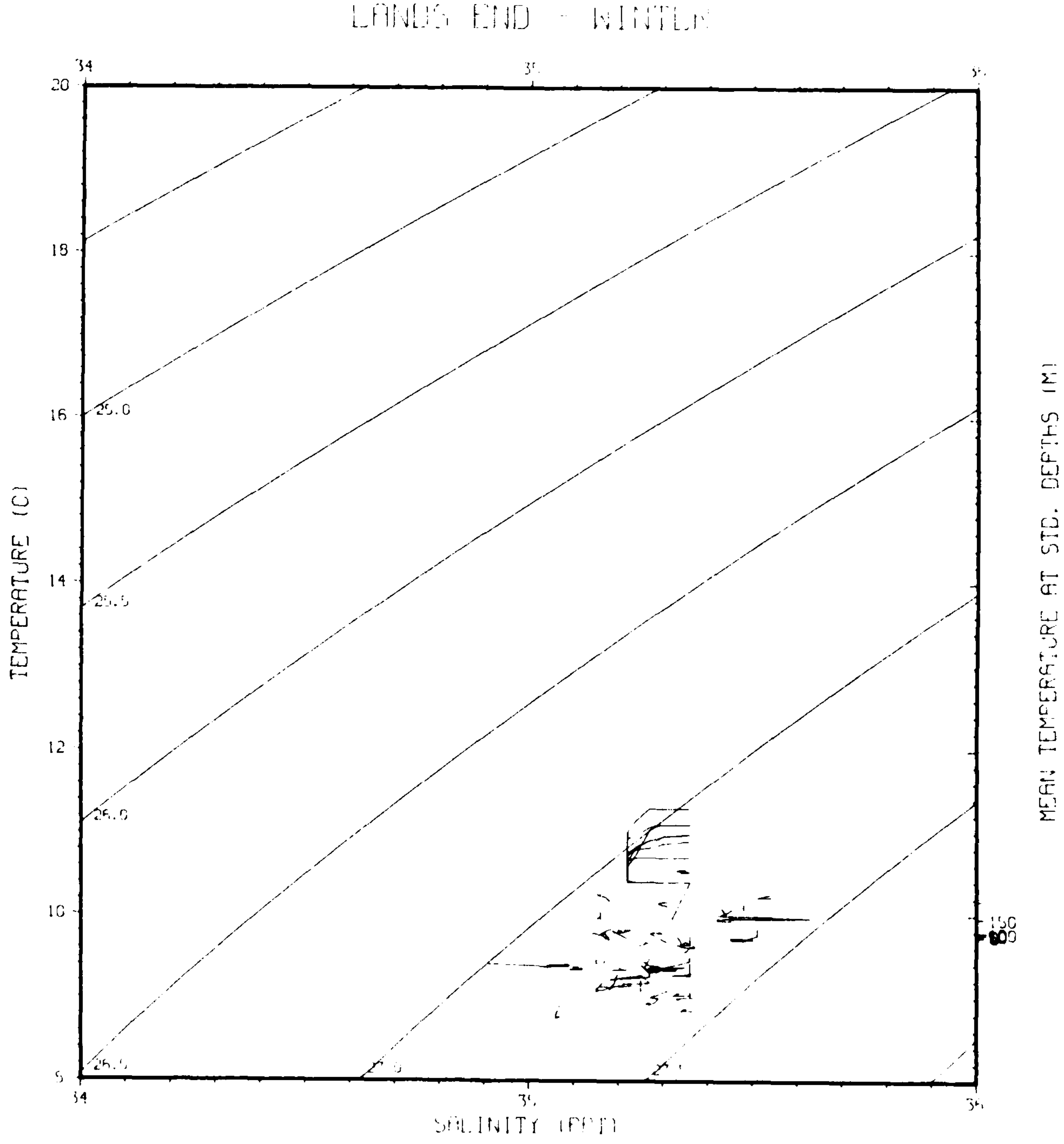
SHALLOW WATER PROFILE GRADIENT SUMMARY

LANDS END - WINTER
TOTAL OBS 50

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	0										
30	0										
50	0										
75	1	2.0	2.0	.017	.017	.017	.000	1488.5	1489.8	90.0	0.
100	25	50.0	52.0	.012	.017	.024	.003	1488.6	1490.1	115.2	6.
125	24	48.0	100.0	.014	.020	.038	.007	1490.6	1493.3	134.9	6.
TOTAL	50										


LANDS END - WINTER
1520
1510
1500
1490
1480



LANDS END - WINTER
TEMPERATURE (C)
SALINITY (PPT)
MEAN TEMPERATURE AT STD. DEPTHS (M)
20
18
16
14
12
10
8
34
35
36
25.0
25.5
26.0
26.5
150
200

LANDS END - SPRINGS

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	15.42	11.23	9.29	1.2040	35.67	35.32	35.03	.1154	1509.1	1495.09	1488.0	4.2008	80
10	15.23	11.01	9.19	1.1766	35.63	35.32	35.02	.1136	1508.7	1494.49	1487.8	4.1416	80
20	14.19	10.74	9.14	1.0326	35.56	35.32	35.05	.1119	1505.5	1493.69	1487.8	3.6877	80
30	13.12	10.38	6.94	.7767	35.57	35.32	35.13	.1056	1502.2	1492.63	1487.2	2.8388	80
50	11.52	9.91	5.50	.5360	35.55	35.33	35.13	.1010	1497.0	1491.27	1486.0	2.0171	80
75	10.83	9.73	8.50	.4216	35.56	35.33	35.15	.1011	1495.2	1491.01	1486.3	1.6297	80
100	10.51	9.68	8.50	.3977	35.53	35.33	35.15	.1006	1495.6	1491.25	1486.7	1.5462	75
125	10.81	9.87	9.13	.3774	35.56	35.37	35.18	.1001	1496.0	1492.40	1489.5	1.4757	38

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

LANDS END - SPRING

TOTAL NO. OF OBS: 80
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 80
MAX: 149 MEAN: 125.3 MIN: 80

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	0	.0	.0	.0
75	5	93.8	85.5	80.6
100	37	100.0	86.4	80.0
125	38	96.2	89.9	83.9
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

DEPTH	POSITIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEGATIVE GRADIENTS (M/S/M) NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NEUTRAL GRADIENTS NO.	PCT OF OBS
20	11	13.7	.025	.015	.010	.0069	68	85.0	.330	.085	.005	.0686	1	1.2
30	6	7.5	.023	.014	.007	.0058	73	91.2	.470	.091	.003	.0665	1	1.2
50	4	5.0	.016	.014	.012	.0016	76	95.0	.368	.081	.002	.0703	0	.0
75	5	6.3	.017	.013	.001	.0064	75	93.8	.259	.059	.004	.0468	0	.0
100	5	6.7	.016	.012	.005	.0046	69	92.0	.189	.042	.001	.0360	1	1.3
125	8	21.1	.017	.008	.001	.0066	30	78.9	.066	.027	.004	.0184	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

SHALLOW WATER PROFILE GRADIENT SUMMARY

LANDS END - SPRING
TOTAL OBS 80

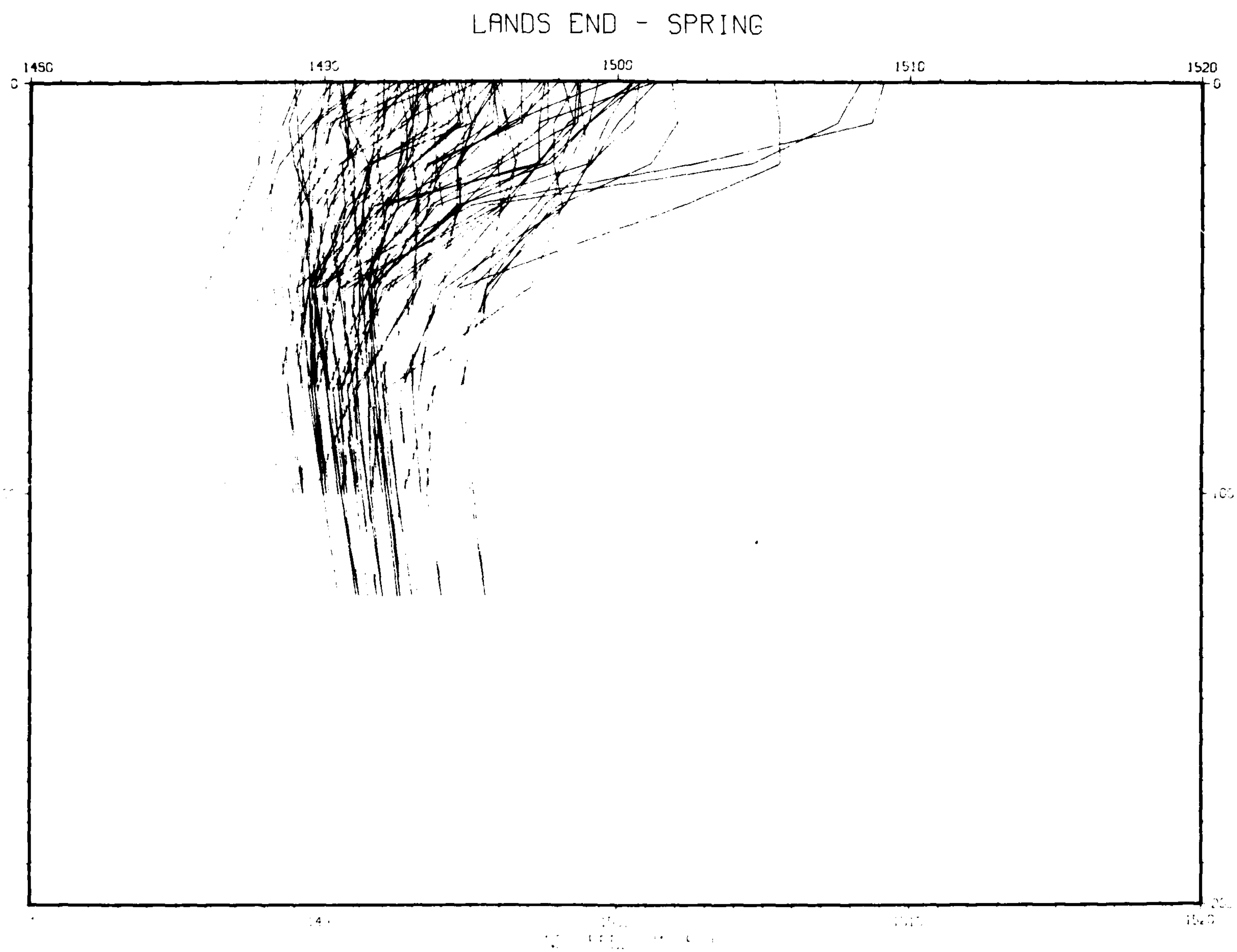
POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	5	6.3	6.3	.010	.016	.025	.007	1496.6	1496.9	119.8	21.
30	2	2.5	8.7	.010	.017	.023	.009	1494.5	1495.0	140.0	3.
50	0										
75	0										
100	1	1.2	10.0	.021	.021	.021	.000	1489.3	1490.7	123.0	0.
125	8	10.0	20.0	.010	.014	.018	.003	1490.5	1491.5	143.1	6.
TOTAL	16										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	2	2.5	2.5	.070	.097	.125	.039	2	2.5	2.5	.016	.018	.020	.003	1491.5	1489.6	112.0
30	3	3.8	6.3	.037	.088	.117	.044	3	3.8	6.3	.011	.014	.017	.003	1492.9	1490.3	121.7
50	22	27.5	33.7	.030	.097	.350	.078	22	27.5	33.7	.010	.015	.018	.002	1495.2	1490.3	121.6
75	33	41.2	75.0	.016	.067	.259	.045	31	38.7	72.5	.004	.015	.020	.004	1496.1	1491.1	124.2
100	4	5.0	80.0	.051	.067	.086	.015	3	3.8	76.2	.016	.020	.024	.004	1498.4	1491.7	129.2
TOTAL	64																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 3, 4.7 PCT OF THE NEG GRAD OBS.


LANDS END - SPRING
1450
1490
1500
1510
1520
0

LANDS END - SPRING

LANDS END - SUMMERS

*** STATISTICAL SUMMARY ***

DEPTH (M)		TEMPERATURE (C) MAX	MEAN	MIN	ST DEV		SALINITY (PPT) MAX	MEAN	MIN	ST DEV		SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM	
0	*	18.22	16.40	12.90	1.1345	*	35.50	35.17	34.76	.1405	*	1517.5	1511.62	1500.8	3.4711	75	*
10	*	18.05	16.19	12.65	1.1589	*	35.50	35.17	34.76	.1322	*	1517.1	1511.08	1500.1	3.5590	75	*
20	*	17.85	15.82	11.75	1.3397	*	35.51	35.18	34.79	.1263	*	1516.7	1510.15	1496.6	4.1538	75	*
30	*	17.30	14.53	10.00	1.9556	*	35.51	35.24	34.89	.1097	*	1514.7	1506.22	1490.8	6.2481	75	*
50	*	15.00	10.62	9.07	.9745	*	35.67	35.33	35.16	.0937	*	1507.8	1497.56	1487.5	3.4425	75	*
75	*	11.76	10.11	8.95	.4158	*	35.59	35.35	35.21	.0837	*	1498.1	1492.23	1487.5	1.5836	73	*
100	*	10.59	10.06	8.82	.3690	*	35.61	35.36	35.23	.0805	*	1496.0	1492.48	1487.5	1.4142	72	*
125	*	10.88	10.19	9.72	.3698	*	35.61	35.38	35.28	.0692	*	1496.3	1493.34	1491.8	1.2270	32	*

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

LANDS END - SUMMER

TOTAL NO. OF OBS: 75
PROFILES REJECTED (TOO DEEP): 0

NO. OF OBS WITH RECORDED BOTTOM DEPTH: 49
MAX: 151 MEAN: 125.5 MIN: 105

PERCENT OF WATER COLUMN COVERED BY CAST

MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	0	.0	.0	.0
75	0	.0	.0	.0
100	29	95.2	85.5	80.0
125	20	95.4	91.1	82.6
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	17	22.7	.030	.014	.005	.0073	56	74.7	.555	.102	.005	.1331	2	2.7
30	9	12.0	.017	.011	.003	.0053	65	86.7	.695	.209	.003	.1913	1	1.3
50	0	.0	.000	.000	.000	.0000	75	100.0	.534	.361	.090	.0976	0	.0
75	0	.0	.000	.000	.000	.0000	73	100.0	.349	.256	.091	.0530	0	.0
100	0	.0	.000	.000	.000	.0000	72	100.0	.259	.191	.075	.0385	0	.0
125	0	.0	.000	.000	.000	.0000	32	100.0	.202	.151	.057	.0313	0	.0
150	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0

SHALLOW WATER PROFILE GRADIENT SUMMARY

LANDS END - SUMMER
TOTAL OBS 75

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

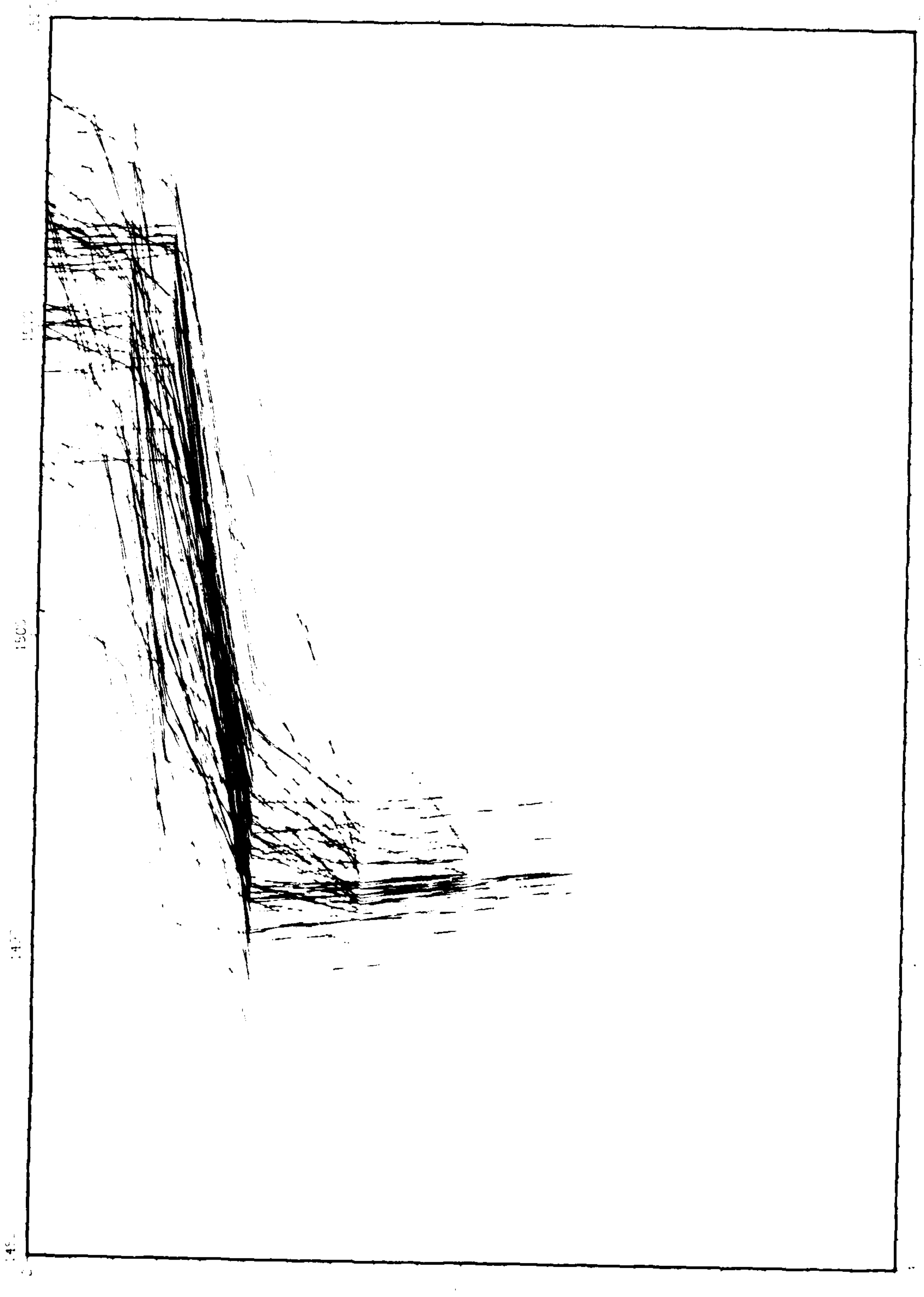
DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	11	14.7	14.7	.005	.016	.040	.011	1512.6	1512.9	133.7	14.
30	9	12.0	26.7	.007	.017	.050	.013	1510.2	1510.5	126.4	15.
TOTAL	20										

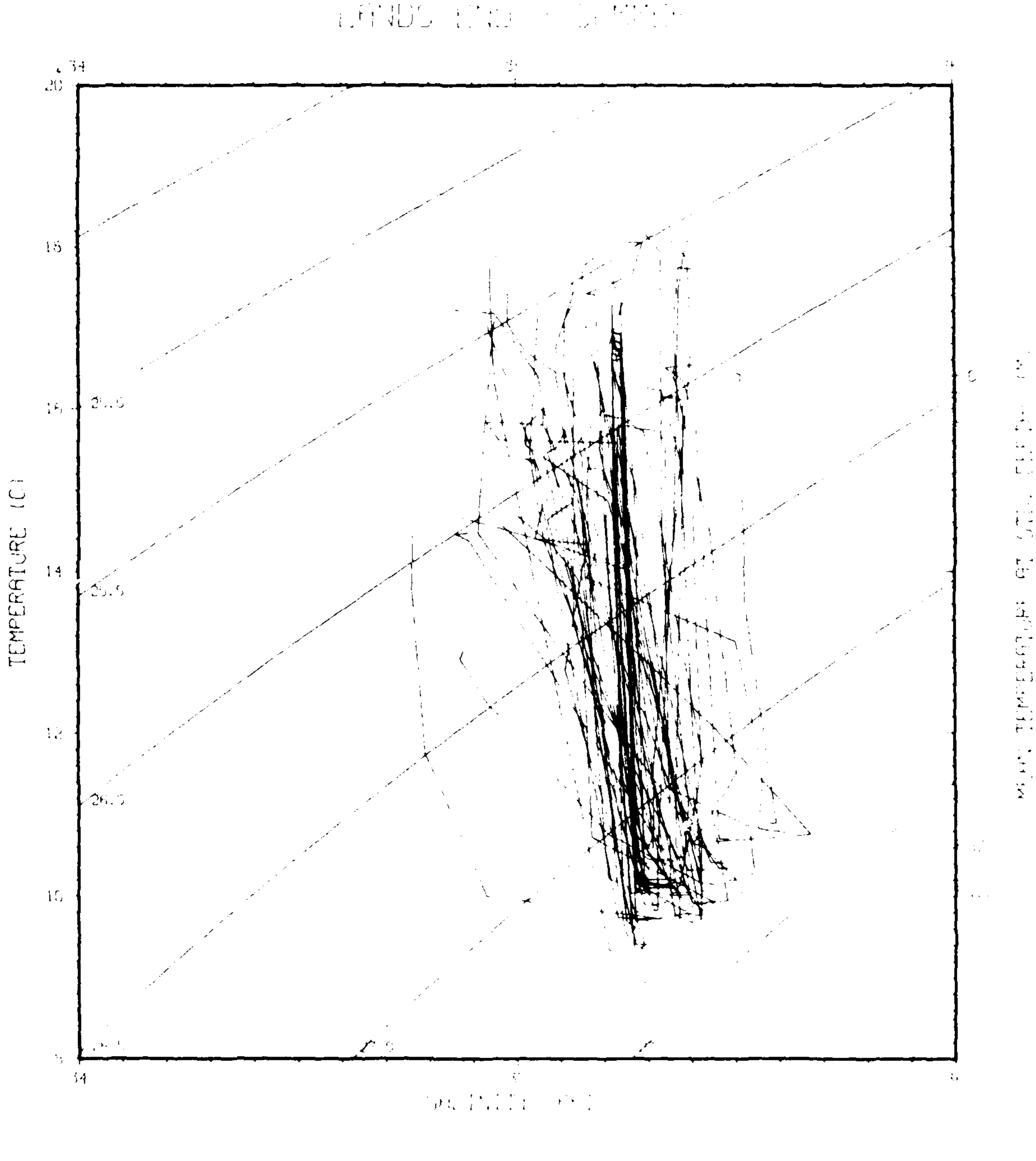
NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	0																
50	27	36.0	36.0	.170	.407	.534	.083	26	34.7	34.7	.006	.015	.020	.004	1511.8	1491.4	114.6
75	22	29.3	65.3	.132	.265	.349	.050	21	28.0	62.7	.012	.016	.020	.002	1512.2	1492.3	117.7
100	6	8.0	73.3	.075	.171	.232	.061	3	4.0	66.7	.012	.015	.016	.002	1509.3	1492.2	107.3
TOTAL	55																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 5. 9.1 PCT OF THE NEG GRAD OBS.

LANDS END - SUMMER




TEMPERATURE (C)

LANDS END - FALL*

*** STATISTICAL SUMMARY ***

DEPTH (M)	TEMPERATURE (C) MAX	MEAN	MIN	ST DEV	SALINITY (PPT) MAX	MEAN	MIN	ST DEV	SOUND SPEED (M/SEC) MAX	MEAN	MIN	ST DEV	NUM
0	16.10	12.54	10.72	1.9616	35.36	35.20	34.75	.1149	1510.4	1500.21	1493.0	6.2922	49
10	16.09	12.55	10.74	1.9863	35.40	35.19	34.75	.1168	1510.4	1500.72	1493.3	6.3200	49
20	16.05	12.53	10.70	1.9840	35.40	35.19	34.75	.1148	1510.5	1500.44	1493.3	6.3034	49
30	16.03	12.43	10.59	1.9799	35.45	35.20	34.75	.1169	1510.6	1500.56	1493.0	6.3068	49
50	15.60	12.23	10.20	1.7245	35.44	35.24	34.93	.0981	1509.7	1495.96	1492.0	5.5739	49
75	14.33	10.84	9.63	.7355	35.44	35.30	35.18	.0545	1506.1	1494.75	1491.3	2.5660	49
100	12.14	10.60	9.66	.4527	35.61	35.33	35.23	.0646	1499.3	1494.38	1491.8	1.6607	48
125	11.87	10.31	9.61	.4557	35.57	35.36	35.23	.0747	1496.8	1494.43	1492.1	1.6150	24
150	11.97	11.97	11.97	.0000	35.32	35.32	35.32	.0000	1499.6	1499.60	1499.6	.0000	1

SHALLOW WATER SOUND SPEED STATISTICAL SUMMARY

LANDS END - FALL

TOTAL NO. OF OBS: 49
PROFILES REJECTED (TOO DEEP): 0

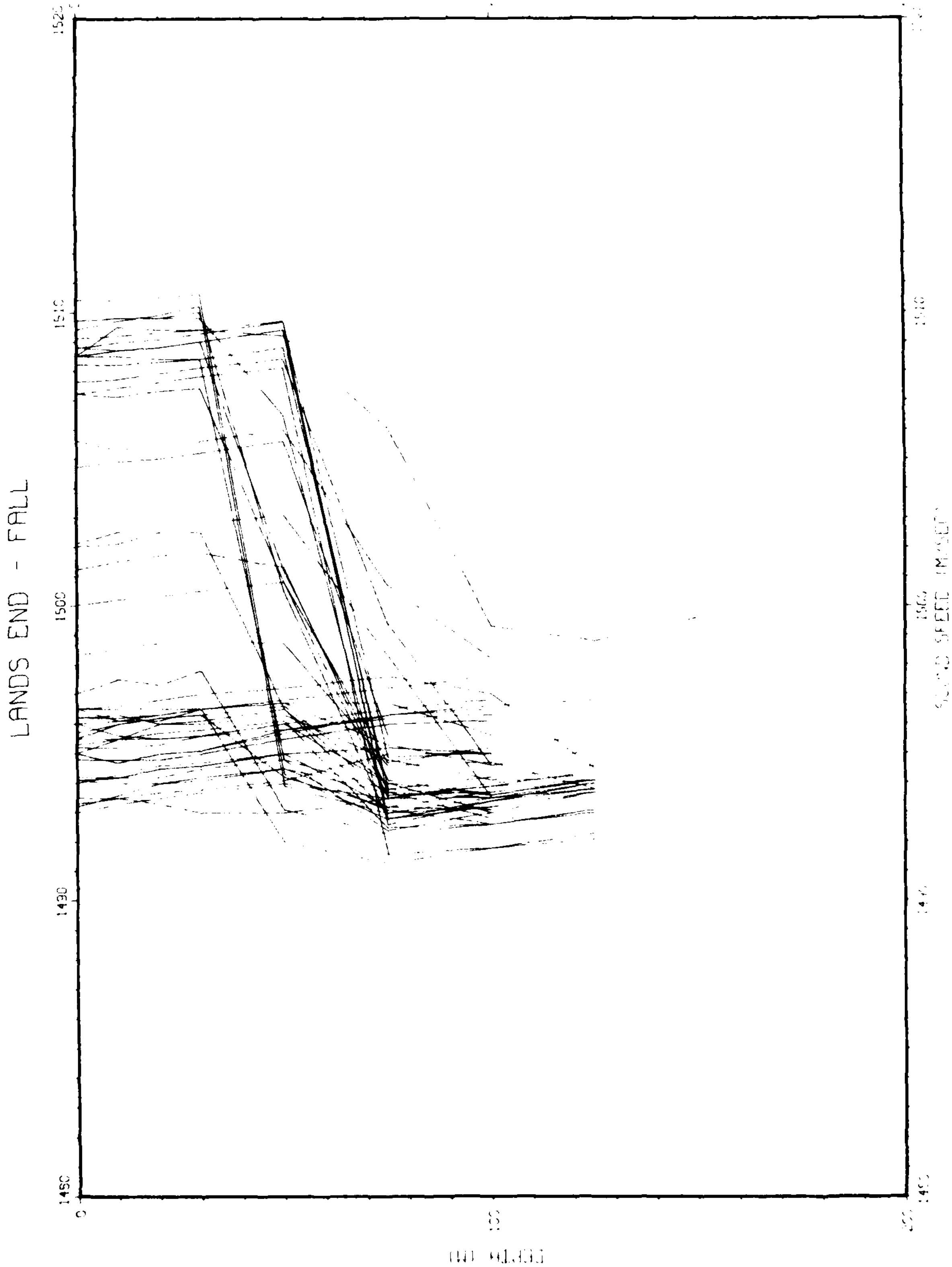
NO. OF OBS WITH RECORDED BOTTOM DEPTH: 33
MAX: 150 MEAN: 123.7 MIN: 105

PERCENT OF WATER COLUMN COVERED BY CAST

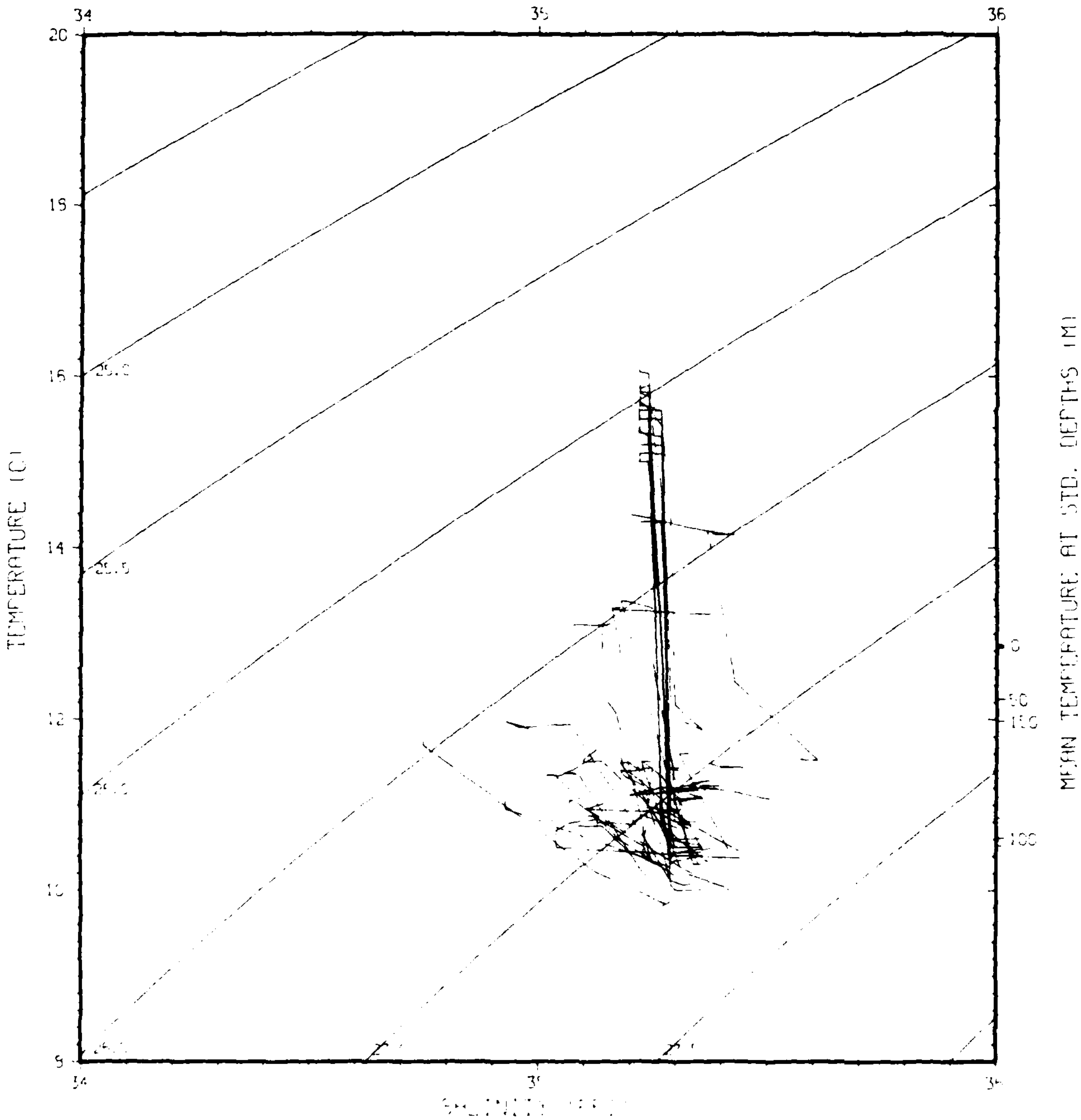
MAX STD DEPTH OF CAST	NO. OF OBS	MAX PCT	MEAN PCT	MIN PCT
20	0	.0	.0	.0
30	0	.0	.0	.0
50	0	.0	.0	.0
75	0	.0	.0	.0
100	20	95.2	86.0	80.6
125	13	99.2	92.9	83.3
150	0	.0	.0	.0
200	0	.0	.0	.0

SOUND SPEED GRADIENTS SURFACE TO STANDARD DEPTHS

	POSITIVE GRADIENTS (M/S/M)						NEGATIVE GRADIENTS (M/S/M)						NEUTRAL GRADIENTS	
DEPTH	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS	MAX	MEAN	MIN	STD DEV	NO.	PCT OF OBS
20	34	69.4	.050	.019	.005	.0114	7	14.3	.025	.011	.005	.0080	8	16.3
30	42	85.7	.033	.015	.003	.0061	4	8.2	.017	.009	.003	.0069	3	6.1
50	36	73.5	.026	.015	.002	.0053	12	24.5	.322	.146	.010	.1065	1	2.0
75	14	26.6	.023	.014	.007	.0042	34	69.4	.235	.111	.003	.0840	1	2.0
100	14	29.2	.017	.011	.003	.0045	33	68.8	.172	.088	.004	.0605	1	2.1
125	3	12.5	.013	.009	.006	.0037	21	87.5	.126	.073	.003	.0445	0	.0
150	0	.0	.000	.000	.000	.0000	1	100.0	.059	.059	.059	.0000	0	.0
200	0	.0	.000	.000	.000	.0000	0	.0	.000	.000	.000	.0000	0	.0


LANDS END - FALL

LANDS END - FALL



SHALLOW WATER PROFILE GRADIENT SUMMARY

LANDS END - FALL
TOTAL OBS 49

POSITIVE GRADIENT (DEPTH OF MAX SOUND SPEED GREATER THAN 10M)

DEPTH OF MAX	NO.	PCT OF OBS	ACC PCT	GRADIENT MIN	GRADIENT MEAN	GRADIENT MAX	STD DEV	MEAN SURF SS	MEAN MAX SS	MEAN BOT DPTH	STD DEV
20	0										
30	12	24.5	24.5	.000	.015	.027	.009	1503.8	1504.2	122.5	10.
50	22	44.9	69.4	.012	.017	.026	.004	1500.6	1501.4	128.1	12.
75	4	8.2	77.6	.009	.013	.015	.003	1495.2	1496.2	115.0	14.
100	7	14.3	91.8	.013	.015	.020	.003	1494.9	1496.3	118.3	2.
125	2	4.1	95.9	.013	.013	.014	.001	1494.3	1495.6	133.0	1.
TOTAL	47										

NEGATIVE GRADIENT (DEPTH MAX SOUND SPEED EQUAL OR LESS THAN 10M)

DEPTH OF MIN	NO.	PCT OF OBS	ACC PCT	GRADIENT TO SURFACE MIN	GRADIENT TO SURFACE MEAN	GRADIENT TO SURFACE MAX	STD DEV	NO.	PCT OF OBS	ACC PCT	GRADIENT BELOW MIN MIN	GRADIENT BELOW MIN MEAN	GRADIENT BELOW MIN MAX	STD DEV	MEAN SURF SS	MEAN MIN SS	MEAN BOT DPTH
0	0																
10	0																
20	0																
30	0																
50	0																
75	1	2.0	2.0	.215	.215	.215	.000	1	2.0	2.0	.026	.026	.026	.000	1508.5	1492.4	.0
100	0																
125	1	2.0	4.1	.078	.078	.078	.000	1	2.0	4.1	.032	.032	.032	.000	1508.5	1498.8	.0
TOTAL	2																

THE NUMBER OF OBSERVATIONS WITH NO DEEP MAX SOUND SPEED IS 0, .0 PCT OF THE NEG GRAD OBS.

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